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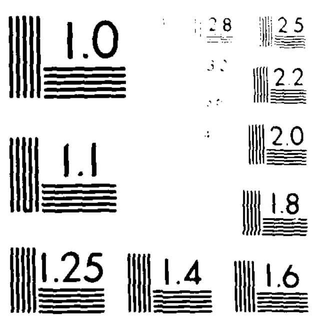

MICROCOPY RESOLUTION TEST CHART

SA ELEMENT 1.4: *IDENTIFY OBJECTIVES HIERARCHY*

We have treated deterrence as the primary objective of NATO AWACS, which contributes to deterrence by providing low-level warning. But deterrence is not achieved solely through low-level warning time. There are other types of warning which contribute to deterrence; and apart from the warning capability, there are other capabilities that contribute to achieving the system objective of deterrence.

An objectives hierarchy needs to be constructed showing the system objective at the top, and the subsystem or sub-subsystem at the bottom, so that we can visualize how the chosen subsystem or sub-subsystem (e.g., NATO AWACS) contributes to the system objective (e.g., NATO deterrence).

We present in Figure 3 the objectives hierarchy. To achieve deterrence, there must be not only warning capability, but also force application capability. Undergirding the force application capability are the economic and political capabilities.

Since our interest is in AWACS, we break down the warning capability into its logical components, such as airborne target warning, ground forces warning, etc., at the next tier below. Among the airborne target warning, we list NATO E-3A as well as alternative sources of airborne target warning, such as ground-based radars and intelligence sources.

This objectives hierarchy is not the only possible hierarchy. The system objective of NATO deterrence can be achieved via different routes, and the purpose is to find the most logical route from the system objective to the particular subsystem or sub-subsystem under discussion.

SA Element 2: Cost

Using this systems approach, the U.S. government position relative to the announced non-participation by a member country in NATO AWACS acquisition would indicate how the system objective of NATO deterrence would be impaired as a consequence. While any change in the announced position would be a political decision, it is essential to develop the technical impairment, such as the loss of 3 minutes of warning time, which could mean the loss of a whole city to the enemy.

SA ELEMENT 2.1: *CALCULATE COST OF CONTEMPLATED ACTIVITY*

We have pointed out that careful calculations of cost have taken into account the fact that much more than the acquisition share would be involved in determining the cost impact of the announced decision. While we exclude the details of the calculation here (as for the same reasons of sensitivity, the details may have to be undisclosed in discussions of similar multinational acquisitions), the aggregate figures themselves should be presented, as we have done.

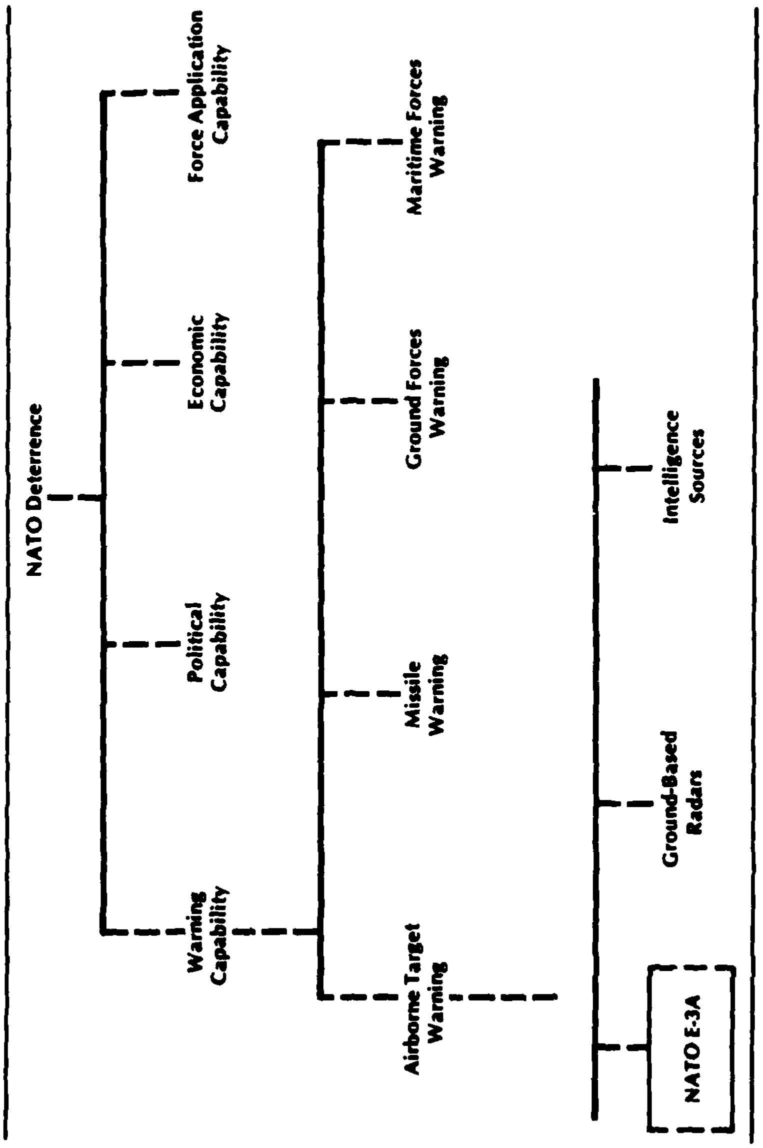

FIGURE 3
Objectives Hierarchy

SA ELEMENT 2.2: IDENTIFY RELEVANT COST ELEMENTS

In his presentation to the American Institute of Industrial Engineers, James E. Williams, Jr., the Deputy Assistant Secretary of the Air Force, indicated a number of cost elements peculiar to multinational acquisitions.

Cost shares determination is an element which is clearly multinational. How much should each participant in the multinational acquisition be required to pay? In the NATO AWACS case, "participation in industrial collaboration and ability to pay" were the key factors.[7]

Divergent national budgeting is another key issue in multinational acquisition. While several NATO nations make long-term commitment to the multinational acquisition, the United States makes annual commitments, with plans for the following years. The national payments for the multinational, multiyear acquisition programs are staggered.

Inflation factor is a serious issue in drawn-out payments. Currencies paid later in the program would have to be deflated to determine their real value against the baseline cost of the program. Late payers would incur higher payments to compensate for inflation. It has been pointed out that the national representatives were unable to resolve the issue during the negotiations preceding the signing of the MMOU, and agreed that they should work out a method. As an interim solution, one late payer agreed to pay inflation through 1981 in the same manner as all other nations, while a longer-term solution was being worked out.

Different fiscal years are another distinguishing characteristic of multinational, multiyear acquisitions. In the case of NATO AWACS, the 13 individual nations observe 8 different fiscal years!

SA ELEMENT 2.3: CALCULATE MARGINAL COST(S)

In Figure 3, we identify ground-based radars as another means of airborne warning capability. If $98 million is denied to NATO AWACS, could that amount be invested in an alternate activity that would support the system objective of NATO deterrence?

A prime purpose of NATO air defense ground environment (NADGE), with ground-based radar facilities from the tip of Norway to the eastern border of Turkey, is the deterrence of airborne attack by Warsaw Pact forces. However, advances in Soviet aerospace technology (e.g., low-level airborne penetration capabilities) have raised concerns about the ability of ground-based systems to respond adequately to such a threat.

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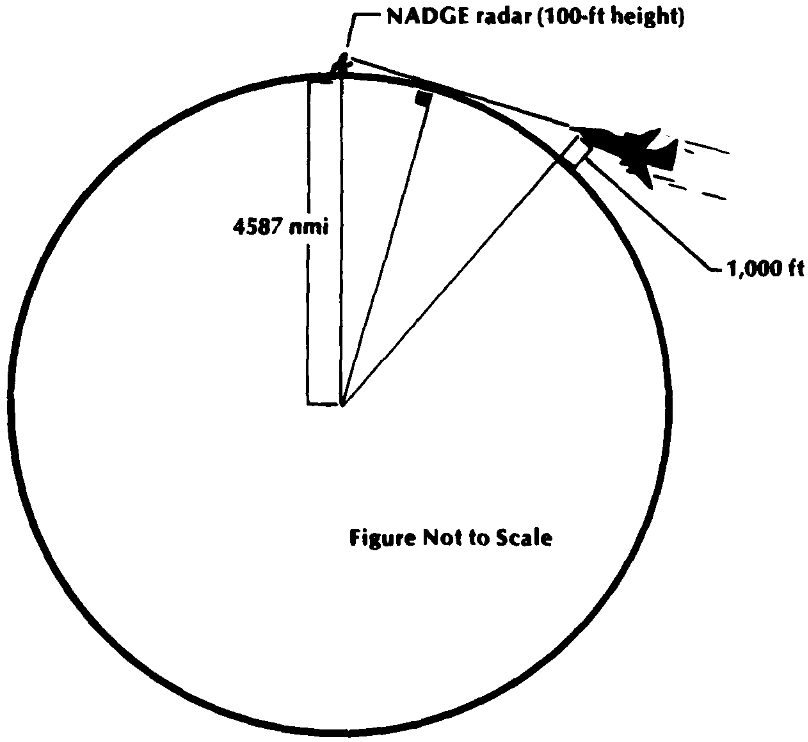
7. James E. Williams, Jr., "Lessons Learned from the NATO AEW&C Program," Address to the American Institute of Industrial Engineers, Washington, D.C., October 23, 1980, p. 4.

FIGURE 4
NADGE Low-Level Radar Line-of-Sight Coverage (1,000-ft target)



In Figure 4, we present NADGE radar with a low-level target at 1,000 feet altitude. Employing the same calculations as we did in the case of the AWACS, we obtain a mean warning time of approximately 7 minutes. The maximum increase in warning time expected from NADGE improvments is 1 minute.

What are the marginal costs? The acquisition budget for NATO AWACS is $1,826 million (1977 dollars). The $98 million amount represents 5.37 percent of that figure. The base budget figure of NADGE is $3,266 million; therefore, the $98 million represents 3 percent of the NADGE base (ignoring inflation).

What would be the operation and maintenance (O&M) costs incurred as a result of the policy activity (i.e., $98 million restored to NATO AWACS), or the alternate activity (i.e., investing $98 million in NADGE)?

Based on NATO MMOU O&M cost estimates, the AWACS element O&M would be $5 million a year to the base of $98 million.[8] The NADGE O&M would also be $5 million a year to the base of $98 million.[9]

SA ELEMENT 2.4: CALCULATE COST OF OPPORTUNITY ACQUIRED

We pointed out that often new capabilities emerge from the new system, such as the capability of the distant early warning system to detect signals from thousands of miles. In arguing for such heretofore non-existent capabilities, marginalism would be inappropriate, because the capability acquired is not that of an additional unit of the same kind.

In multinational acquisition, the very fact of joint action may suggest an *opportunity acquired.* Since the first delivery of E-3A to NATO is scheduled for February 1982, and since nothing similar to the low-level warning capability of AWACS has been employed by the NATO countries, we may consider a heretofore non-existent capability to emerge with the employment of NATO AWACS.

SA Element 3: Effectiveness-Absolute

The third element in systems approach is effectiveness-absolute. The measure of effectiveness of the system is the measure of the performance measure of the system—which we identified above as the warning time. The measure of warning time is simply the quantity (amount). We already discussed the number of minutes involved, viz., 3 minutes of additional warning of low-level aircraft.

SA Element 4: Effectiveness-Relative

By how much is the effectiveness changed corresponding to changes in subsystem or sub-subsystem inputs?

We can combine the effectiveness-relative with cost, insofar as the relative change in effectiveness is achieved at a cost. The decision to make the investment in the input depends not only on what the effectiveness change is, but also on how much it costs.

SA ELEMENT 4.1: COMPUTE COST EFFECTIVENESS—POLICY ACTIVITY

Cost effectiveness is simply effectiveness divided by cost. Cost comprises fixed cost and variable cost. In Table I, the cost effectiveness parameters for both the policy activity and the alternative activity are shown.

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8. Assistant Secretary General for Defense Support, "Multilateral Memorandum of Understanding (MMOU) between NATO Ministers of Defense on the NATO E-3A Co-operative Programme," HQ NATO, Brussels, Belgium, December 1978, p. 36.

9. Derived from USAF SAGE System O&M Estimates, HQ, USAF/XOX.

TABLE I
Cost-Effectiveness Parameters—NATO E-3A, NADGE

			NATO E-3A	NADGE
EFFECTIVENESS	Baseline[a] warning time[b]		24.2 min	7 min
	Increased warning time		2.7 min	1 min
	Total warning time		26.9 min	8 min
COST	Fixed Costs (FC)	Baseline acquisition	$1,726,000,000	$3,266,000,000
		Incremental acquisition	$ 100,000,000	$ 100,000,000
		Total acquisition	$1,826,000,000	$3,366,000,000
	Variable Costs (VC)[c]	Baseline Operations and Maintenance (O&M)	$1,500,000,000	$5,100,000,000
		O&M attributable to incremental acquisition	$ 75,000,000	$ 255,000,000
		Total O&M	$1,575,000,000	$5,355,000,000

[a]NATO E-3A: 16 aircraft; current NADGE system.
[b]Warning time refers to warning provided against low-level airborne targets
[c]Estimated life-cycle costs.

The effectiveness measure in the case of policy activity is the 2.7 minutes increase in warning time. To achieve it, there is the fixed cost of $98 million and the variable cost of $75 million. Rounding the $98 million to $100 million for ease of computation, we have the cost effectiveness of NATO AWACS as a result of restoring the $98 million given by:

AWACS Cost Effectiveness $= 2.7 \text{ minutes}/(\$100 \times 10^6 + \$75 \times 10^6) = 1.5 \times 10^{-8}$ min/$

SA ELEMENT 4.2: COMPUTE COST EFFECTIVENESS—ALTERNATE ACTIVITY

The effectiveness measure in the case of NADGE, the alternative activity, is 1 minute. To achieve it, there is the fixed cost of $98 million (rounded to $100 million) and the variable cost of $255 million. The cost effectiveness of the alternative activity is given by:

NADGE Cost Effectiveness $= 1 \text{ minute}/(\$100 \times 10^6 + \$255 \times 10^6) = 2.8 \times 10^{-9}$ min/$

SA ELEMENT 4.3: COMPUTE COST EFFECTIVENESS—ABSOLUTE BASE

The measure of effectiveness used has been the increase in warning time. Since the objective of deterrence is best served by the absolute warning time, let us consider how the cost effectiveness analysis fares in that case:

AWACS Cost Effectiveness $= 26.9 \text{ min}/(\$1.826 \times 10^9 + \$1.575 \times 10^9) = 7.9 \times 10^{-9}$ min/$

NADGE Cost Effectiveness $= 8 \text{ min}/(\$3.366 \times 10^9 + \$5.355 \times 10^9) = 0.9 \times 10^{-9}$ min/$

Systems Approach to Resource Allocation

The cost effectiveness analysis shows that the restoration of the $98 million to NATO AWACS is more cost-effective than investing the $98 million in NADGE. AWACS is 8.8 times as cost effective as NADGE.

Resource Allocation—Initial Weighted Scores

The investment in one or the other activity is to further the system objective, i.e., NATO deterrence. How should the elements of the objectives hierarchy be related to one another in order to justify the restoration of the $98 million?

The concept of "penalty for non-fulfillment" is found to be useful in incorporating value judgments into the allocation of resources. Penalty for non-fulfillment is the adverse effect upon the system objective of not carrying out an activity at the subsystem or lower levels.[10]

We start with a horizontal comparison of activities at the bottom tier of the objectives hierarchy in Figure 3. We have three elements: (1) NATO E-3A, (2) ground-based radars, and (3) intelligence sources. Which of the three will cause the worst penalty to the system objective if not carried out? The *least* critical choice gets a lower score than the *more* critical choice, which gets a lower score than the *most* critical choice. Clearly, the scores reflect one's subjective judgment. Treating intelligence sources as the least critical among the three, let us give it a score of 3 on a scale of 0–10. Since we are advocates of AWACS, that system gets the highest score of 9. Ground-based radars are given a slightly higher score of 4 than the least critical one of intelligence sources.

These three choices are all elements of airborne target warning. Recognizing that we could have overlooked a fourth or fifth choice at the lowest tier, we allow for it (them) by multiplying the sum of the three scores, i.e., $9 + 4 + 3 = 16$, by 1.5 to give a score of ($16 \times 1.5 =$) 24 for airborne target warning. This methodology is applied to the other hierarchical steps.

How much worse is it not to have airborne target warning (ATW) at all, as compared with not having NATO E-3A? Since E-3A is only one of the three elements of ATW, the whole should be given more importance than the individual parts. One way of doing this is to give the lowest tier a weight of 10 and the next higher tier a weight of 10^3, indicating that ATW is 100 times as important as AWACS. Non-linear weights are assigned to the different levels to reflect the fact that it is much more serious to leave unfulfilled a higher-level objective. Since the system objective fulfillment is the ultimate criterion, the penalty score of the

10. George K. Chacko, *Systems Approach to Public and Private Sector Problems*, North-Holland, Amsterdam, The Netherlands, 1976, Chapter 4.

policy activity (AWACS) is expressed in terms of the penalty for non-fulfillment of the system objective of NATO deterrence. How much money is there to allocate to AWACS? The total allocation for NATO deterrence is more than $160 billion—the NATO defense budget. In Figure 5, we show the *trial* allocation of resources.

The purpose of the initial allocation is to make a system check, so to speak. Are all the elements and their interrelationships taken into account? The *numerical* results are much less important than the *conceptual*.

Resource Allocation—Revised Weighted Scores

Clearly, the $1,229 trial allocation would not buy NATO AWACS. How should the different elements in the objectives hierarchy be related to each other in order to justify the restoration of the $98 million to NATO AWACS?

In our initial allocation of weights and scores, we considered economic capability (reflected in GNP) as contributing a certain value to deterrence (e.g., through scientific technology, electronics, aerospace elements) at, say, one-tenth. This value was then compared to the expenditures for warning capability to arrive at a penalty score for non-fulfillment approximately double the sum of the penalty scores for these two choices. Two principal changes are introduced in the revised allocation of scores and weights of penalties for non-fulfillment. The first is the revision of the penalty score for "economic capability," which is revised downward from 500 to 97. The second is the revision of the vertical weights. Since NATO E-3A is a Priority 1 NATO requirement, the penalty for non-fulfillment of E-3A could be considered close to that of NATO deterrence itself. The results of the revision and the consequent resource allocation appear in Figure 6.

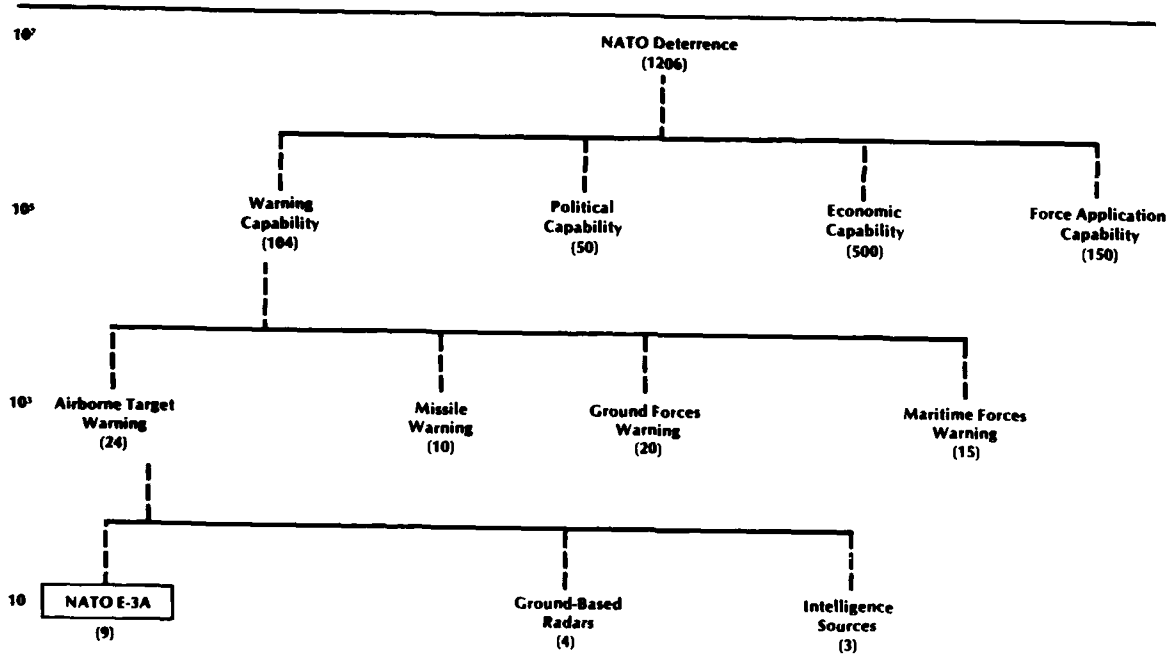
What the revised allocation has shown is that the resource allocation authority has to be persuaded that the weights of political and economic capability should not be 50:500, but rather 25:97. In other words, *political capability* is given 2.5 times as much weight as in the initial allocation. The results, viz., the agreement, first in principle, then in full by the member country to participate in the NATO AWACS acquisition leads us to conclude that the rationale of resource allocation has been acceptable to the resource allocation authorities.

Proven Usefulness in Multinational Acquisition

The methodology of systems approach as illustrated by a NATO AWACS problem analysis suggests that it can indeed be valuable for other multinational acquisition problems of a similar nature.

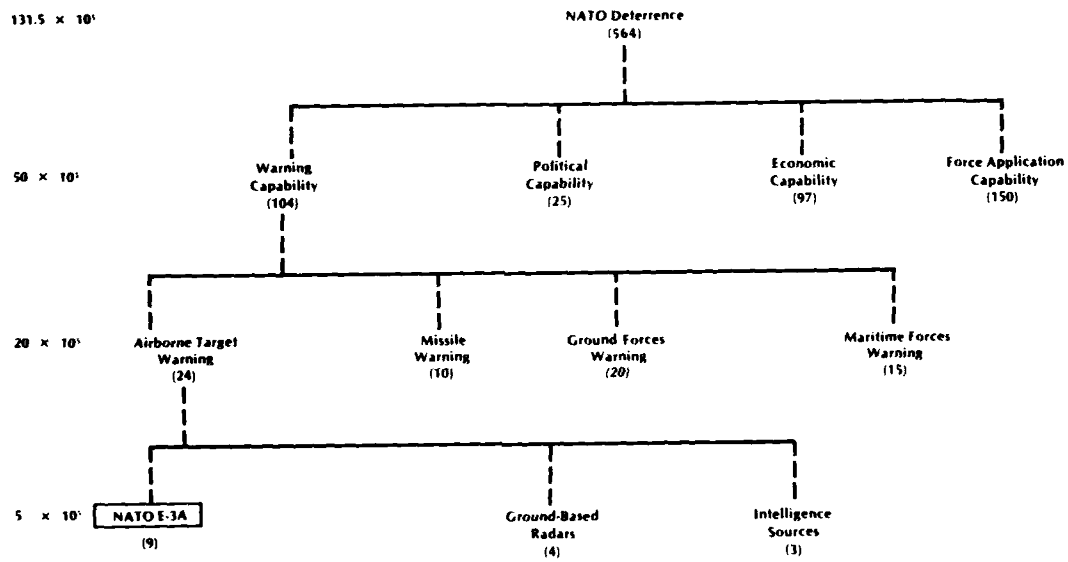
The ultimate test of the value of multinational acquisitions is, of course, the furtherance of the system objective. We hope that our discussion indicates that

FIGURE 5
Initial Allocation of Resources to NATO E-3A



$$\text{Allocation to Nato E-3A} = (\$164.7 \times 10^9)\,\frac{(9 \times 10)}{(1206 \times 10^7)} = \$1229$$

FIGURE 6
Revised Allocation of Resources to NATO E-3A



$$\text{Allocation to NATO E-3A} = (\$164.7 \times 10^9)\left(\frac{9 \times 5 \times 10^5}{564 \times 131.5 \times 10^5}\right) = \$100 \times 10^6$$

systems approach reasoning can prove helpful in clarifying the issues, choices, and consequences of alternative options from the potential impairment of the system objective. At that high level of common interest, accommodations for the common good are, perhaps, perceived as acts of prudence.||

107 Scheduling for Program Management: How and Why

Forrest L. Godden, Jr.

So you want to be a program manager? Good. You are one. You have put aside your pencil, triangles, and T square and have assumed one of the most demanding jobs in your organization. You lean back in your chair with a satisfied smile because you have just completed laying out your project schedule. You feel assured your program will be 100 percent successful because you have covered all the angles. And even though experience has shown that everything takes longer than expected, you are optimistic that *this time* things will be different. Sound familiar? In fact, the odds are that you are in schedule trouble before you even have a chance to identify your problems. It is a safe assumption that much of the program lead time will be absorbed in the technical and administrative processes of defining the requirements and the program.

Program schedules are usually backed in to fit an inflexible initial operating capability (IOC) date, with the probability of success practically nil. When developing schedules, the following assumption has to be made: Nothing works right the first time; everything goes wrong, and everybody makes mistakes.

Why Do We Need Schedules?

Because program management provides centralized authority over technical and business aspects of a program, your job as program manager covers many disciplines. You must coordinate, manage, and direct the development and production of a system to meet performance and schedule. You must meet cost objectives defined by his service and approved by the Secretary of Defense (SECDEF). You are the agent of your service in the management of the system acquisition process. You must focus the authority and responsibility of your service for running the program. You have the vantage of a broad perspective of the program and the interrelationships among its elements. You are the motivating force for propelling the system through its evolution. Every weapon system competes with all others for limited resources, and competition is especially fierce in periods of tight budgets. The program manager who has done his homework and kept key people informed about his system's progress and problems will maintain program balance and improve the odds that funds for his program will not be reduced.

Program balance is the recognition that there is an inescapable interplay among the three basic program elements—technical performance, time, and cost. You cannot talk about *what* is wanted without also talking about *when* and *how*

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much can be spent. You must be aware that the balance struck at the beginning of the program can seldom be maintained throughout the development. New facts, new technology, new threats, and unexpected cost all act to upset the old balance and require the formulation of a new one.

Maintaining a balance may also be described as limiting the amount of resources committed to the program in the event the results of development efforts require that the program be substantially redirected or even cancelled. The technique for obtaining this balance embraces these interrelated activities:

—Assess the risk implicit in alternative subsystem and system development concepts. Avoid alternatives involving low probabilities of success. Reassess risks periodically during the development process.

—Reduce, to the maximum extent possible, concurrency in risky situations.

—Demonstrate mastery of high-risk elements before proceeding into successive program phases.

—Control changes and be sure all schedule and cost implications of a proposed change have been evaluated.

—Plan for unknowns.[1]

Schedule problems are not always externally thrust upon the program office; some develop from within. It is a natural tendency of scientists and engineers, whether in industry or in government, to seek technical perfection, the consequence being to regard schedules as of secondary importance. You must emphasize that schedules are primary—perhaps even more important than the last measure of small improvement in technical performance. Design engineers love to fiddle and tinker and, if left to their own devices, it can be guaranteed there will be schedule slippages and cost problems. An absolute deadline must be set. Much can be accomplished once it is understood that no additional time will be made available.

The term "management information systems" is familiar. The schedule function is an integral part of any good management information system. Unfortunately, management *systems* are frequently mistaken for *management*. This mistake is most evident when people speak of management *control* systems, which really do not control anything. "Management information systems" is more appropriate because these systems provide data which may be used to focus on those items that are out of control, as well as to assist the manager in planning project activities, scheduling activity occurrence times, and controlling project progress in terms of cost, schedule, and technical performance. Project planning involves the determination of activities to be accomplished and their sequence of

1. "Introduction to Military Program Management," Logistics Management Institute, March 1971.

accomplishment. Scheduling involves the specification of dates and times for performing these activities. Controlling is a measurement and comparing process.

Developing and Constructing a Schedule

Scheduling is the accomplishment of the "when" element in maintaining program balance. It is coming to grips with the hard detail of program execution. Schedules establish the basic program objectives that are expected to guide the planning process, and are also used by the program manager to maintain a balance between dollar commitments and program risks. Peter C. Sandretto, in his book, *The Economic Management of Research and Engineering*, emphasized the importance of planning and scheduling when he wrote:

> After all has been said and done about systems to control engineering costs and performance after the decision is made to embark on a project, it is the project plan prepared before starting the work that determines to a major extent the outcome of a project in terms of time, cost, and technical performance. Almost universally, there has been a lack of realization that, once a project plan is accepted, the die is cast. Further action can help to steer the course of the project and possibly conduct a rescue from disaster, but the road sign to the disaster point was erected when the project plan was written. But why was the plan faulty? The answer to this question is complex and not at all evident. There are many reasons for faulty project plans. Perhaps the outstanding cause is a lack of recognition of the importance of these plans. . . . To be sound, a project plan must be produced through a systematic, detailed analysis that includes breakdown of the project by components, tasks, work packages, events (milestones), and approaches, rather than by the procedure known as SWAG (Systematic Wildly Assumed Guess).[2]

There are many project management techniques available to aid you in planning and scheduling a specific project. These differ in type as well as in the quantity of output information being generated for controlling project cost, schedule, and technical performance. The emphasis is on which types of information items are desired or required for satisfactory project control.

Work Breakdown Structure

One of the most useful management tools for project managers is the work breakdown structure (WBS). Managers need total program visibility and timely

2. Peter C. Sandretto, *Economic Management of Research and Engineering*, John Wiley & Sons, Inc., 1968, pp. 91, 105.

data on program progress and problem areas. A work breakdown structure provides the framework for the required management visibility and data reporting in a manner directly related to systems engineering and the manner in which the work is to be accomplished.

As the term implies, a WBS breaks a total job or program into component elements; these elements can then be displayed to show their relationship to each other and to the program as a whole. A programmed WBS results from the systems engineering effort during development and production of a particular system. It provides a schematic portrayal of the products (hardware, software, services, and other work tasks) that completely define the program. It provides a means for effective management planning and implementation by providing the functional managers of a program or project with a common reference framework for communicating as well as making decisions. A WBS should be broken down into elements that completely define the task to be accomplished. In effect, the elements of the WBS define the basic objectives of the task by identifying: (1) subtask of the level required for visibility; and (2) associated interrelationships necessary to accomplish the task. Each WBS element should be selected to permit assignment of responsibility to an organizational entity so that accountability can be established. Moreover, each individual WBS element, at the lowest level, should be further broken down into work packages that describe specific tasks of relatively short duration to again enable proper visibility and control. It is essential that work packages be established in a manner that will provide sufficient and proper management information for program/project control. Additional criteria for establishing an effective work package would include the following: (1) represents specific definable unit of work; (2) defines unit of work at level where work is performed; (3) relates unit of work directly to, and as an extension of, a specific element of the WBS; (4) assigns unit of work to a specific single organizational element; (5) limits each unit of work to a relatively short span of time; and (6) identifies specific accomplishments (outputs) to result from unit of work (reports, hardware deliveries, tests, etc.).

Establishing Milestones

Once the WBS is developed, the next step is establishing milestones for the project. A milestone is a key activity or event that takes place over a period of time in a project and must be clearly defined. Milestones are not elastic events that can be stretched by emotional rhetoric or tailored by fancy to fit the situation.[3] They are events whose successful accomplishment will be demonstrated

3. "Introduction to Military Program Management," Logistics Management Institute, March 1971.

evidence of progress toward the program goals. The use of milestones in planning and controlling systems acquisitions is not new; they occur in every program and are used by decision-makers at all levels. As a program manager you will use a large number of schedule milestones to manage your program, but will focus your attention basically on the *key* milestones. These are the events of special significance used to provide progressive assessment of the reduction of risk, and to see that commitments are based on *actual*, not *planned*, accomplishments. In this manner, decisions which commit funds or reduce available program options will be based on events and not calendar dates. Key milestones have two basic purposes:

—In planning a program—to structure the program so progressive commitments are made only when justified by the remaining level of program risk.

—In managing a program—to assure that the premises on which program commitments were originally planned have been validated, or proven, before additional commitments are made.[4]

Two points regarding milestones need to be emphasized. First, set enough milestones to ensure that if problems do arise not too much time will have passed without their being noticed, and that enough time or slack will be available to recover from them. The shorter the period between milestones, the easier it will be to keep track of progress and recover from shortfalls. Second, avoid designing a system that either ends up being a reporting nightmare, or is so tight that creative people lack the leeway to do a job. Milestones must be frequent enough to keep on track, but spaced far enough apart to get the work done.

Other Scheduling Factors

Still other factors need to be evaluated when developing a schedule. Planning for unknowns is essential. Unknowns come in two varieties: anticipated unknowns (or known-unknowns) and unanticipated unknowns (or unknown-unknowns). The latter are usually called "unk-unks." Planning for unknowns is the substance of risk analysis and is basic for orderly risk reduction in a program. The possibility of failing to meet a schedule task can be treated by recognizing that some slippage is the inevitability of some degree of schedule slippage. For this reason, as noted earlier, the schedule must allow some breathing room (slack time) to accommodate it. Also, in order to schedule well, you must know the nature of the work. Scheduling consists essentially of organizing the work, therefore, it is necessary to know in detail what follows what, who will do what, and who will make sure it is done. It is also important to know the kinds of skills needed and what people are available for various periods of the schedule. Predic-

4. *Ibid.*

tions may be rough, and it may be necessary to act *ad hoc*, but by realistically organizing the work ahead of time, there is a better chance of minimizing a shortage of people or resources at a crucial point.

Some scheduling techniques most suitable to project managers are Gantt charts (bar chart), line-of-balance (LOB), and networks. Gantt charts provide a single, deterministic estimate for when project activities are to begin and end. Gantt charts are good in repetitive work because time estimates are historically established and production is easy to count. They are easy to understand, to accept, and to implement, and are easy to update if the program is static. But, Gantt charts are not effective for large, complex projects. They cannot simulate alternatives and do not readily show ability to meet schedules if many interrelated tasks are involved. Line-of-balance is used principally for scheduling production effort. One advantage of this technique is that, because the work is repetitive, completion time estimates are more accurate. Line-of-balance compares favorably with the Gantt chart technique, with the disadvantages that it is not always understood, it does not emphasize resource allocation directly, and there is no capability to simulate alternatives.

Networking Systems

Networking systems like the program evaluation review technique (PERT) provide information on earliest/latest start and finish times for activities, float or slack time, critical path activities, and the probability of successfully meeting a schedule completion date. Techniques such as graphical evaluation and review technique (GERT), and the venture evaluation review technique (VERT) allow even more sophisticated schedule control by treating both the occurrence and time of project activities as random variables.

A major strength of the network technique is that it forces a manager to think about possible problems because of the necessity to trace exactly how things will work. As one program manager put it:

> Getting involved in the networking gives you a feel for the whole program. You get an understanding beyond the "buzz" phrases. You can see the relationships among things, and most important, you can talk intelligently about your whole program—why you are doing things and when they must be done. You get a feeling of confidence about your group of the program that is communicated to others. They, in turn, get a sense of confidence in your ability to manage your program. When people up the chain don't have that sense of confidence, you find that they take over the program. . . .[5]

5. *Ibid.*

As a program manager you must consider the relationships among a number of activities. You must identify tasks and decide which activity takes precedence, which activity has to be finished before another can start, and which activities can be done simultaneously. This requirement for detailed thought will force you to anticipate requirements that might be overlooked on a bar chart. One of the key advantages of a network is that the network itself provides insight understood by most people. Networks are used principally in R&D effort and are used extensively by the U.S. Army Corps of Engineers in construction projects. Networking also allows the manager a chance to simulate the effects of alternative decisions at a number of points; moreover, he gets a better appreciation of the critical series of activities (the critical path) in which a weak link could seriously damage the project. He is also able to assess those paths of the network where there is slack (float) which will offer flexibility as the schedule changes. This critical path is not always obvious, and often scientific and technical people are shocked when their idea of the critical path is not confirmed. The network technique gains its strength because it allows the manager to display many ideas about how the project will proceed, and allows him the flexibility to rethink as he encounters problems and unknowns, and as he gains experience. Networks allow simulations, where a manager can input changes in the schedule and activities, and evaluate the effect these changes might have on the total project or system. Networking allows evaluation before, rather than after, the fact.

Selecting a Technique

What is the best planning or scheduling technique for you? Unfortunately, there is no cookbook answer. The selection of a project scheduling technique or complete management information system is a difficult and a potentially costly decision. For this reason, you cannot arbitrarily select a technique or simply use the same one over and over. To find the best technique, a logical, structured approach has to be used. This is not an easy decision because of the number and the diversity of techniques, which vary in cost, complexity, input data requirements, output information items, timeliness, equipment requirements, etc. The lack of clearly defined selection criteria also makes this decision difficult. Most project management literature is descriptive in nature. The characteristics of one or two techniques are described, but nothing is offered to assist the project manager in selecting a particular technique. As a result, the selection is normally based on what has been used before, techniques known by the project manager's staff, or on what the boss or customer requires.

There are criteria you may use in selecting management techniques. These are as follows: (1) *accuracy*—the system should provide accurate information, i.e.,

progress reports should reflect genuine progress; (2) *reliability*—progress data should be consistent regardless of who collects it or when it is collected; (3) *simplicity*—easy to explain and understand, and simple to operate; (4) *universality of project coverage*—one scheduling system should be sufficient for the entire project; (5) *decision analysis*—provide information on alternative courses of action; (6) *forecasting*—forecast ability to accomplish future tasks; (7) *updating*—capable of rapidly and easily incorporating information on project progress; (8) *flexibility*— capable of being adapted to change in the project; and (9) *cost*—provide required information at the lowest cost. Although these criteria are important considerations, their apparent subjectivity makes it difficult, if not impossible, to quantitatively assess the merits of one project management technique over another. Consideration must be given to the nature of the project and the desired characteristics of the management technique. What is the value of criteria such as accuracy, reliability, simplicity, etc., if the selected technique does not provide the specific management information you require?

Reporting Systems

Equally important to the scheduling technique is the reporting system. Besides a written plan, a system of reports concerning the progress of a project is necessary. The advantage of having a formal reporting system is not that it provides an accurate measure of progress (for it may capture only superficial aspects of the project), but that it gives a common point of departure in discussions about what really is going on regarding the project. Caution: The reporting system must be timely; a report that is received late does not allow proper reaction time to correct deficiencies and only adds to the existing problems.

Schedule control consists of comparing actual activity completion times against scheduled completion times. The purpose of schedule control is to keep the project manager informed of potential as well as actual schedule slippages. Planning and controlling are closely related. In part, they are so closely related that there exists a tendency to assume the system used to control the program determines the kind of detail of planning which should be done. This is wrong. It may be decided, based on the scope of the program, that a sophisticated control system like PERT is not required; however, it is still necessary to lay out in extreme detail what is to be done.

Besides the formal reporting system for tracking projects, it is necessary to simply communicate. This is important because almost every project manager is responsible for many areas in which he is not an expert; by frequently discussing those areas with knowledgeable people, he gets a better base from which to evaluate problems. And, last but not least, a project manager usually gets some

insight about how well a project is going if he talks with the user or customer about what they need or expect.

Conclusion

In summary, there is no cookbook answer. Even managers who value planning may feel there is not enough time, or that the main processes and problems seem so obvious that planning is not needed. Unfortunately, a manager will tend to overlook problems if he does not put on paper those things that must work right. It has been said that one way to evaluate how a manager is going to carry out his work in a project is to learn how he thinks about it, i.e., how he plans it. If the manager does not appreciate the problems he may have later on in a program, it is quite possible he will not recognize them even when they surround him.||

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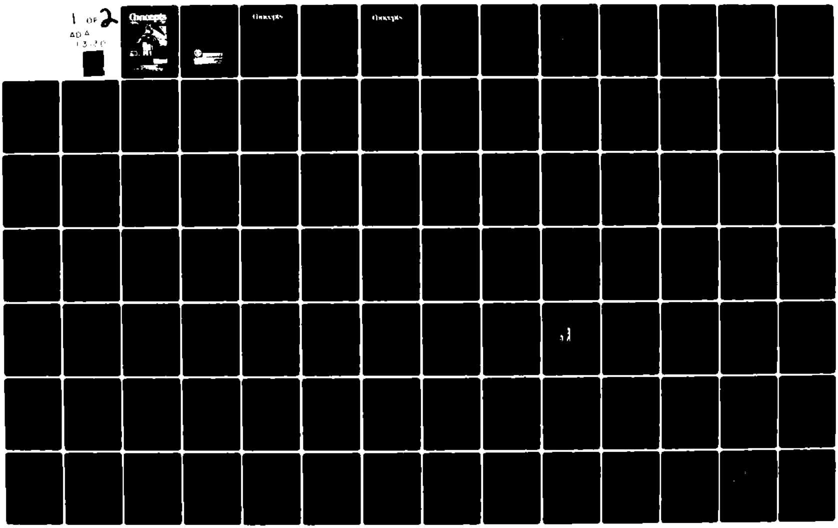

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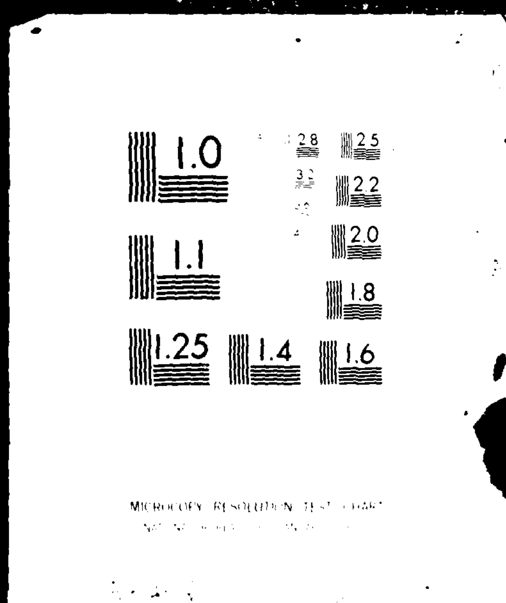

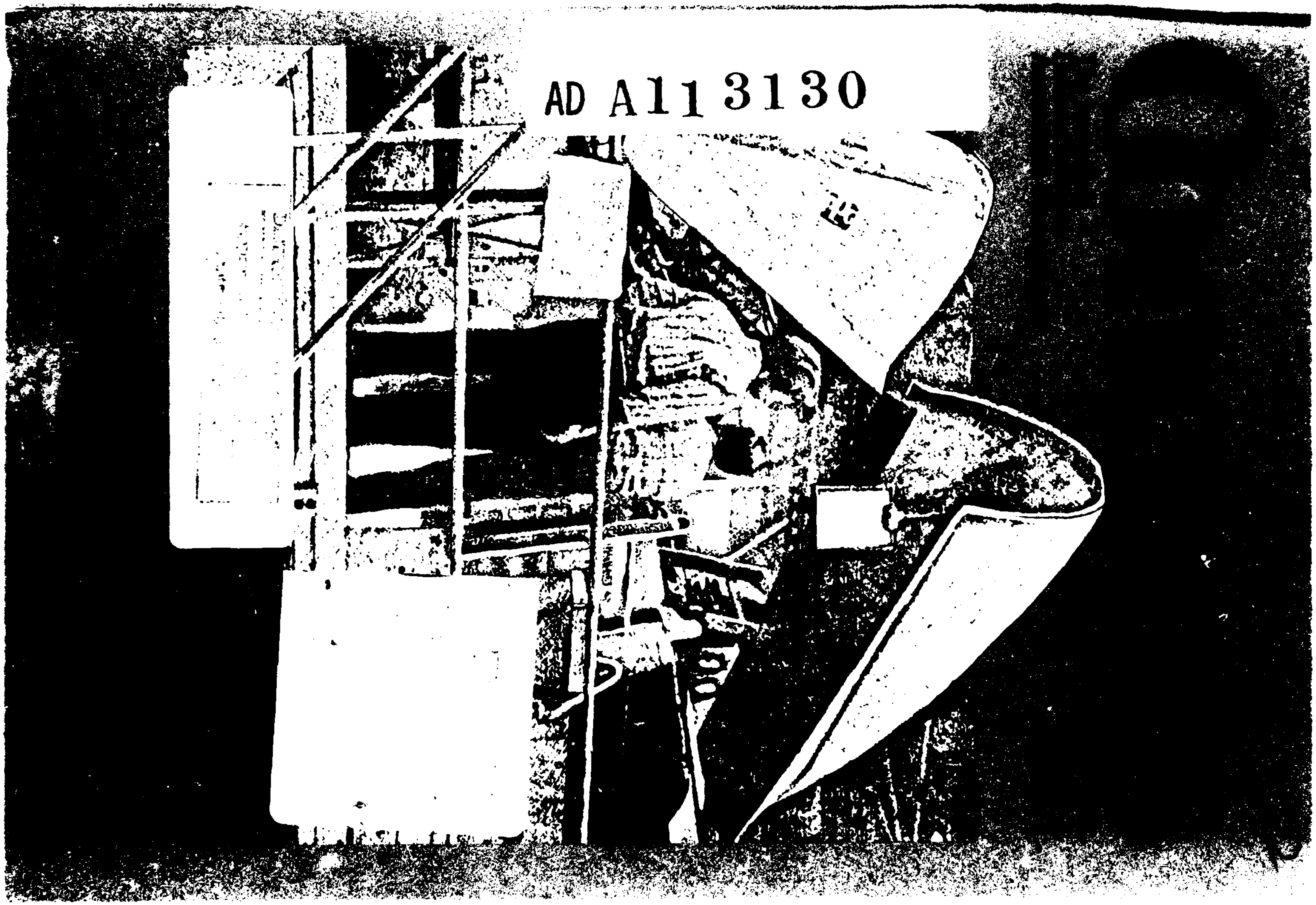
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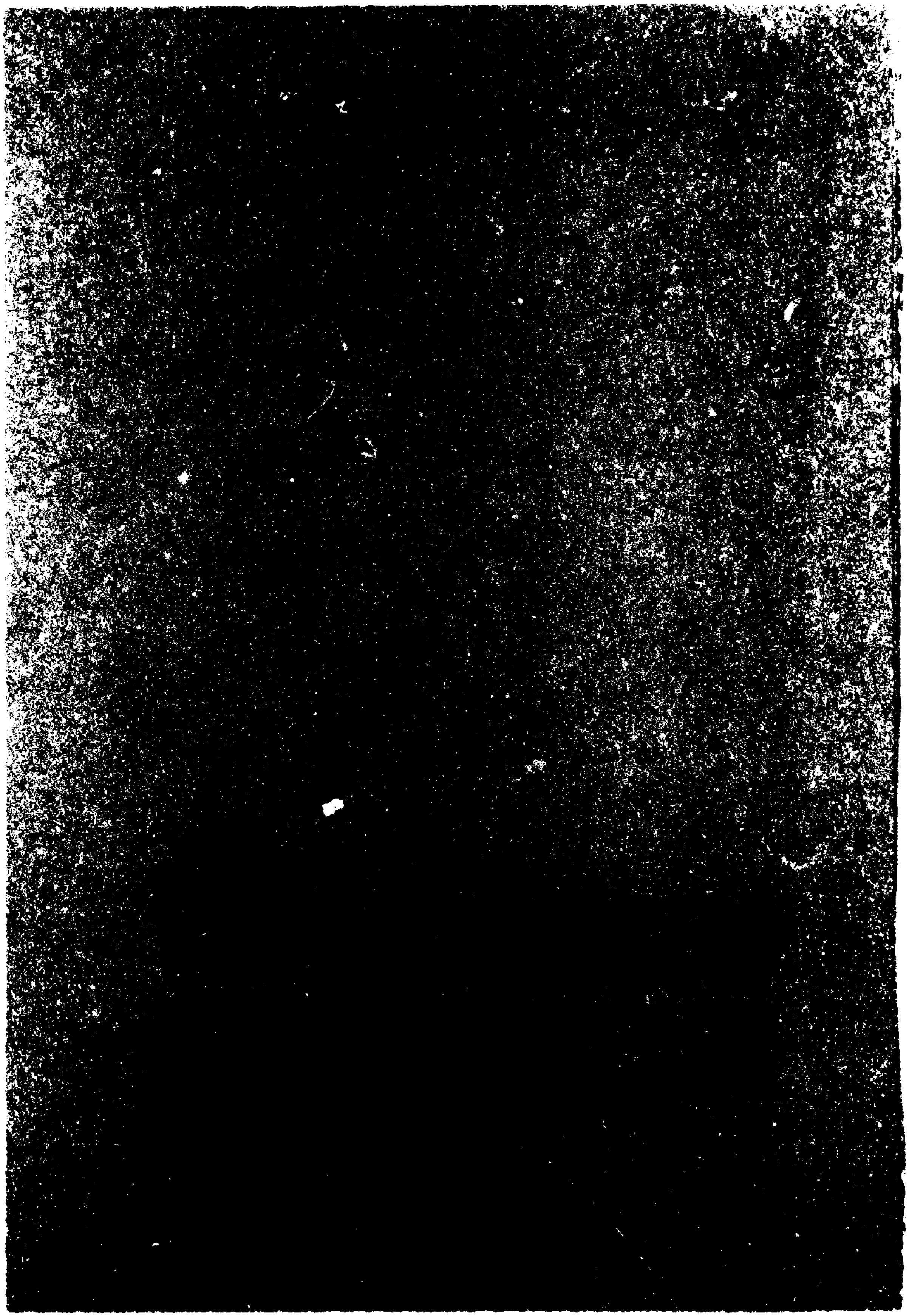

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7 Financing Defense System Programs — *Dr. Franz A. P. Frisch, David D. Acker*

One reason cited for the excessive length and cost of the DOD acquisition process is the relatively small number of companies willing to participate in defense business. The authors argue that this already small number is decreasing still further because of government policies that have led to undercapitalization in defense business. They offer recommendations for changes in government policy designed to remedy this situation through enhanced contractor financial stability.

29 Evaluating the Impact of Quantity, Rate, and Competition — *Larry W. Cox, Dr. Jacques S. Gansler*

The authors have developed analytic methodology incorporating the interrelationships of cost improvement curves, production rate variations, and competition on the production costs of weapon systems and subsystems. They discuss the methodology and provide an example that indicates potential applications of the methodology to system acquisition planning and decision-making.

54 Department of Defense Acquisition Improvement Program — *Colonel G. Dana Brabson, USAF*

In March of 1981, Deputy Secretary of Defense Frank C. Carlucci chartered five working groups to identify the most significant problems in DOD acquisition and to recommend solutions. Out of this effort came 32 actions to improve defense acquisition. The author discusses these actions and the changes in management philosophy they reflect.

76 Human Factors in Weapon Design: The Performance Gap — *Dr. Jonathan Kaplan, John L. Miles, Jr.*

Testing of military systems gives evidence that those systems rarely perform to their designed potential. The authors contend that this "performance gap" is the result of a lack of attention being given to human factors during the system design process. They provide evidence to support this view and offer suggestions for improving human factors input.

90 **Systems Approach to Multinational Acquisition: NATO AWACS**
Dr. George K. Chacko
Lieutenant Colonel Bruce N. Stratvert, USAF (Ret.)

In 1978, NATO defense ministers approved a program for the acquisition of E-3A airborne early warning and control systems (AWACS) aircraft. In 1979 a member country announced a decision not to participate in the program. The authors outline a systems approach to determining the impact of this non-participation in an effort to draw lessons for other multinational programs.

107 **Scheduling for Program Management: How and Why**
Forrest L. Godden, Jr.

One of the most important, if most difficult, tasks the program manager faces is the establishment of realistic, achievable schedules. The author discusses the importance of good planning and scheduling and offers advice on carrying out this essential management function.

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from the editor...

For the past few months there has been a great deal of activity surrounding the Department of Defense acquisition improvement program. The program consists primarily of 32 actions mandated by the Deputy Secretary of Defense and designed to resolve some of the more obstinate problems in defense systems acquisition. DSMC has been very much involved in this program almost since its inception last spring. Members of the research staff have developed briefings to "get the word out" on the improvement program, and are taking to the road to explain the 32 actions to acquisition commands and other interested parties across the country. For an overview of the program and a brief discussion of the individual actions, see page 54, "Department of Defense Acquisition Improvement Program."

In the Publications Directorate we have our own improvement program under way. Our objective remains one of bringing *useful* information to the acquisition manager, while at the same time providing a forum for new, creative, non-conventional, even controversial ideas for better managing defense acquisition programs. Some months ago, we established the *Concepts* Editorial Board so that we would have available to us the expert criticism and advice necessary to keep us on the right track in terms of meeting the needs of our audience. We selected for the Board two program managers from each of the services and three representatives from defense industry, all who graciously agreed to serve for a period of two years.

The Editorial Board members review each issue of *Concepts* and comment on its usefulness, interest level, etc. They supplement this critique with advice on subject matter, treatment, and format. Many of the recommendations already made by Board members will be put into effect with later issues.

In another matter related to improving *Concepts*, we are developing a readership survey designed to provide information that we can use to further improve our product. If you receive one of our survey questionnaires, please take a few moments to fill it out. It may be your best opportunity to tell us if and how well we're meeting your needs.

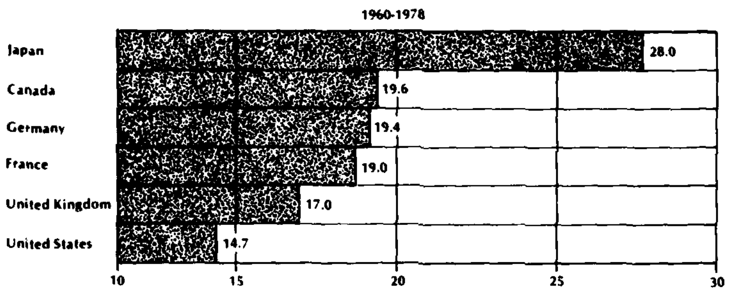
With this issue we bid farewell to Brigadier General William E. Thurman, USAF, who for the past two and one-half years has served as DSMC Commandant, and who is now moving on to the Aeronautical Systems Division, Wright-Patterson AFB, Ohio, where he will become Deputy for the B-1. General Thurman has been a strong supporter of DSMC publications since coming to the College, and has provided the command emphasis and guidance that has allowed the publications program to prosper. We of the publications staff are grateful for his support and wish him the best in his new assignment.

7 Financing Defense System Programs

Dr. Franz A. P. Frisch
David D. Acker

United States defense industry is currently under-capitalized. For example, defense contractors have been investing in new plants and equipment at only about 60 percent of the rate of all the manufacturing industry in the United States, and at about 30 percent of that of *all* U.S. enterprises. For American productivity to increase, a large portion of the resources available in the United States should be going into capital investment in all industries. This has not been the case in recent years; in fact, the United States now ranks sixth in the industrial world (see Figure 1) in terms of the percentage of gross national product (GNP)

FIGURE 1
Average Annual Rate of Capital Investment as a Percent of Output*



Source: U.S. Department of Labor, Office of Productivity and Technology, July 1980. Presented by George A. Strichman, chairman, Colt Industries, Inc., to House Ways & Means Committee July 29, 1980.

*Excludes residential building

Dr. Franz A. P. Frisch is Professor Emeritus of the Defense Systems Management College and Adjunct Professor at Virginia Polytechnic Institute and State University. He has 30 years' experience in shipbuilding and related subjects in Austria, Denmark, Sweden, Germany, and the United States. Dr. Frisch holds engineering degrees from the Technical University of Vienna, Austria.

David D. Acker is Professor of Acquisition/Program Management at the Defense Systems Management College. Prior to joining DSMC, he was assigned for 3 years to the Office of the Director, Defense Research and Engineering, where one of his responsibilities was the development, coordination, and communication of policy associated with major defense systems acquisition. Mr. Acker spent 23 years in industry in design engineering, project engineering, and program management associated with Air Force, Navy, and Army contracts. He has taught engineering and management courses at Rutgers University, VPI, and UCLA, and is the author of numerous articles on management, design, and communications. Mr. Acker holds B.S. and M.S. degrees in mechanical engineering from Rutgers University.

going into capital investment. Have we forgotten that capital investment was the key that unlocked the door to our prosperity?

Today we find that competition for this limited capital is causing a problem. Contractors are obligated to their shareholders to put the capital where it is going to produce the best return on investment. Also, because defense business tends to be unstable and to produce generally low profits, more and more companies in defense industry have been seeking business in the non-defense sector. Some companies have pulled out of defense business altogether.

Inflation, the cost of borrowing money, unfavorable depreciation laws and tax policies, and cash flow problems have all combined to discourage investment. When all of these factors are taken into account, it becomes apparent that the government needs to take a close look at current defense contracting practices and government regulations and then take some positive action. The flow of contractors, subcontractors, and suppliers out of defense business must be stopped. Companies now in the defense marketplace should be encouraged to stay in it, and other companies should be persuaded to enter it.

This decrease in the number of companies doing defense business has had the effect of increasing the cost of defense system programs and lengthening the acquisition process. On one large program in a 12-month period, there was a turnover of approximately 2,500 subcontractors and suppliers out of 6,000. On one large aircraft program, the prime contractor received only 60 percent as many bids this year as he received last year.[1]

One of the principal actions that might be taken to encourage additional companies to enter the marketplace, and to arrest the flow of companies out of it, is to revise the current DOD contract financing policy. This is suggested because there is a growing concern that the current policy is adversely affecting the earnings, credit capacities, and reinvestment abilities of defense systems contractors.

In preparing this paper, we have recognized the current concerns, the erosion of the defense industrial base, and the needed mobilization potential in the United States, and have accepted the challenge of analyzing the financing of defense systems programs and of suggesting what might be done to solve some of the problems that now exist.

Analytical View of Current Approach

Before such an analysis can be made, it is important to understand how contract financing is carried out; therefore, we will try to state in simple analytical terms the current approach to financing.

1. Report by Defense Science Board Industrial Responsiveness Task Force, 15 August 1980.

To begin, we will examine the two extremes that are possible in contract financing situations. These extreme situations in themselves may or may not be real; however, in the real world, most contract financing situations will share some of the characteristics of these two extremes.

Extreme Situation 1: Party A (the government) orders from Party B (the contractor) a certain number of end products, and pays for all of the end products *in advance* (Pa), that is, at the time the contract for the end products is signed.

Extreme Situation 2: Party A (the government) orders from Party B (the contractor) a certain number of end products and pays for all of the end products at *the completion of the contract* (Pc), that is, after all of the end products have been delivered.

Between the two extreme situations, all of the variations of down payments, progress payments, deferred payments, and the like, as well as any conceivable combinations of these payments, occur. These extreme situations can be diagrammed so as to present a linear progression from one extreme to the other.

The extreme situations just described will allow the contractor to take two extreme actions in response to the nature of the payments made.

Extreme Contractor Action 1: In the situation in which the purchase price,[2] Pa, is paid as soon as the contract is signed, the contractor does not have to prefinance his effort, either with his own money or with borrowed money, to ensure a sufficient cash flow throughout the contract. The cost of money is not a problem for the contractor, and no financial action is needed to ensure that his funds will be sufficient to carry out the contract.

Extreme Contractor Action 2: In the situation in which the purchase price, Pc, is paid at the completion of the contract, the contractor must completely finance his effort, either with his own or borrowed money, to ensure a sufficient cash flow throughout the contract. In either case, the cost of money is a problem for the contractor. When he uses his own money, he will lose opportunities to do other things with it. When he borrows money, he will have to pay interest. In either situation, the contractor will have to ensure that there is sufficient cash flow to perform the contract.

When either of the extreme contractor actions is taken in response to the extreme financing situations, a correspondingly high or low business cost will result. Business costs, as used here, may be defined as the total money out-flow of a contractor for such things as material, labor (wages and salaries), and overhead (capital equipment, depreciation, capital reserve, insurance, and the cost of borrowing money). This may also be called the true cost, regardless of whether the

2. To keep the analysis simple, it has been assumed that the purchase price of the end product encompasses all possible inflationary conditions.

FIGURE 2
Logic Diagram of the Extremes

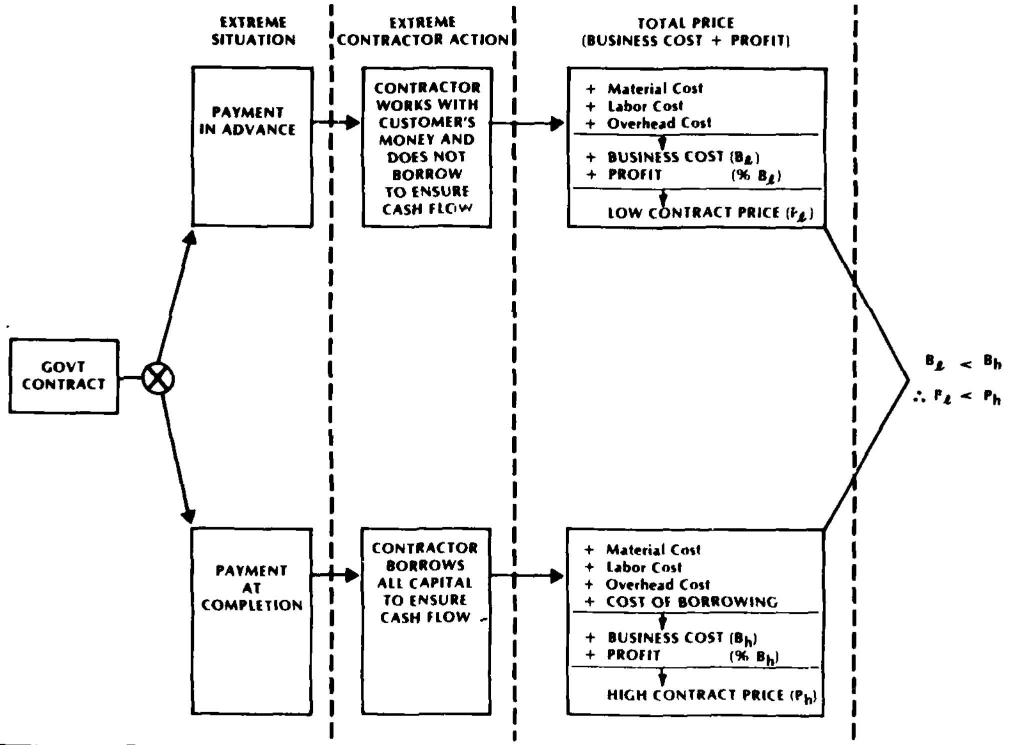
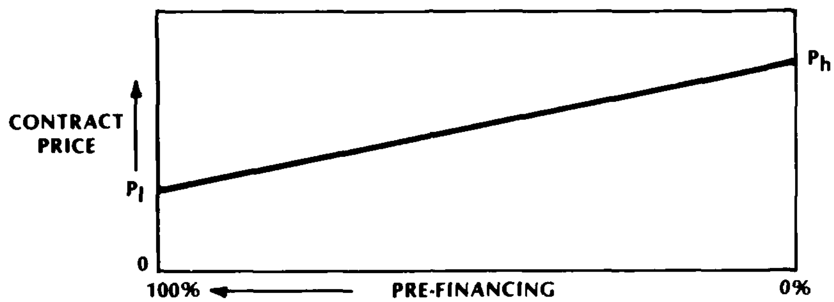


FIGURE 3
Linearity of Prices



cost is legitimate under the current tax laws or contract laws and regulations. Considering the last qualifier—the cost of borrowing money—the term "business cost" encompasses more than what we generally take into account in the conventional definition of the total cost of a project or program.

A risk assessment needs to be made against the business cost. The normal practice is to translate the risk into profit—the profit necessary to accept the risk or, at least, to make the risk a valid gamble.

The definitions of the extreme contract prices can be generalized and presented in a logic diagram (Figure 2). In establishing the low contract price, the low business cost—also known as risk cost for profit or risk compensation—is the sum of the generic production factors: material, labor, and overhead costs. The low contract price, then, is the sum of the low business cost and a percentage of the low business cost (profit). In establishing the high contract price, the high business cost is the sum of the generic production factors and the cost of borrowing. The high contract price is the sum of the high business cost and a percentage of the high business cost (profit). Because the pre-financing can be applied from 0 percent up to 100 percent of a contract, the linearity between the two extremes may be shown in Figure 3.

The Supply Breakdown Structure of the Manufacturing Process[3]

The linearity of prices or costs is valid only so long as a single contractor

3. The idea for the supply breakdown structure is from a forthcoming book, *The Structure of the Industrial Base*, by F. A. P. Frisch, 1981.

TABLE I
Levels of Products

PRODUCT LEVEL	NAME OF PRODUCT AND PRODUCT DEFINITION	PRODUCT EXAMPLES	KEY ACTIVITY AT EACH LEVEL
I	SYSTEM The end product	ship, aircraft, tank, missile	Assembling system
II	SUBSYSTEM A subassembly of the end product; a major subdivision of the end product	engine, bilge, airconditioning unit, gun, avionics	Assembling subsystem
III	COMPONENT A fundamental constituent of a subsystem or an end product; a number of elements joined together to perform a specific function and capable of disassembly	carburetor, pump, heat exchanger, audio-frequency, amplifier	Assembling component
IV	ELEMENT A fundamental constituent of a component or a subsystem; one piece, or a number of pieces joined together which are not normally subject to disassembly without destruction	screw, gear, rotor, front-wheel bearing, frame	Making element
V	MATERIAL The basic ingredient (material) from which an element is produced	fuel oil, plate, wire, casting	Refining and/or forming material
VI	RAW MATERIAL The refined (or untransformed) material	ore mine, oil field, forest	Extracting raw material

fulfills the entire value-added operation, i.e., one contractor converts the raw materials into the end products. When subcontractors and suppliers become involved, the linearity of prices or costs no longer prevails. As soon as one or more subcontractors and/or suppliers enter the manufacturing process, and there is no prefinancing, the multiplier affect of the risk peregrinates throughout the structure of the process.

For a major defense system, there are frequently six levels of products, beginning with the raw materials (Level VI) and ending with the system itself (Level I). The six product levels are shown in Table I. The activities at Levels V and VI are distinct; however, the making and assembling activities at Levels I through IV represent a continuum, the complexity of which varies from product to product. For example, an assembly in one instance may be a subassembly in another where it forms a portion of an assembly.

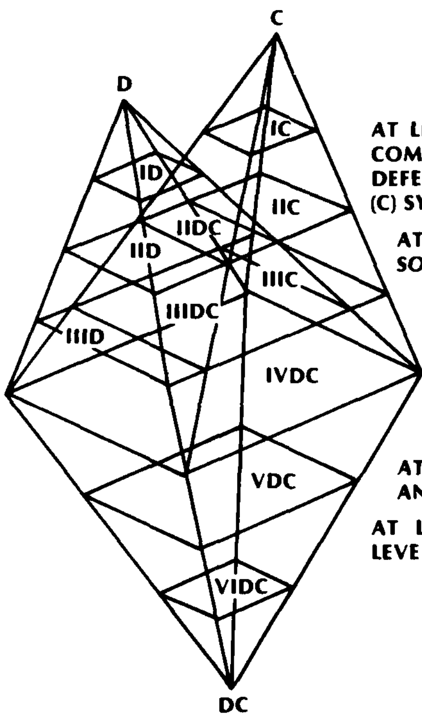
If the products at each level of the supply breakdown structure are counted, there is justification for representing them with a double pyramid. The fewest products will appear at each apex, i.e., raw materials (Level I), and systems (Level VI). Most of the products will appear as elements (Level IV). Going a step further, let's consider the compatibility between completely different industries, say the defense and commercial industries. Here no differentiation is possible between the two industries at the lower levels (Levels I through III); however, at the upper levels (Levels IV through VI) these industries may have very little in common. Figure 4 illustrates this point.

If one were to take a vertical slice through the double pyramid in Figure 4, one would find a specific product with its processing activities taking place at the various levels of a supply breakdown structure. Such a slice might be displayed as indicated in Figure 5. This structure contains most of the ingredients needed to make an analysis of products and services. Such an analysis can flow from the end product to the raw material, or from the raw material to the end product. The structure is timeless and ubiquitous for any product and any service—past, present, or future. The symbols used in the structure represent the subdivisions of labor, material, and capital at various stages in the manufacturing process.

Figure 5 displays the breakdown structure for a defense system as observed from the end product (P) back to the source (S) of the raw materials(s) (Level VI). At each product level, beginning with Level I, labor (L) combines the capital (C) in order to add value to material (M). This results in a product (P) which, in turn, enters the next higher level in the structure as material. Again, labor and capital combine to add value to the material at this new level. This process continues until the resulting system (end product) emerges at Level VI.

Now, let's reverse our view. Let's look from Level VI (raw material suppliers) towards Level I (prime contractor). This view is presented in Figure 6. The pro-

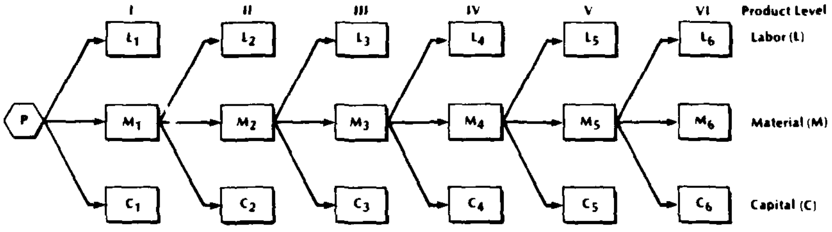
FIGURE 4
The Industrial Pyramid



duct of Level VI consists of L_6, M_6, and C_6. Those who contribute these factors constitute the business volume at this level. Conducting business at this level entails risk (R_6). We have used risk at any level in the structure as a catch-all item in our simplified analysis. What we call "risk" might be associated with necessary profit, cost of borrowed money, or any intangible item such as inflation. The point to be made here is that risk R_6 enters Level V hidden in material M_5. At Level V, the risk R_5 occurs. Risk R_5 is not only based on L_5, M_5, and C_5, but on R_4, which has already been shifted into M_5.

This process of shifting the risk cost of the lower level into the material cost at the next higher level continues up through the entire hierarchy of the supply

FIGURE 5
Supply Breakdown Structure of the Manufacturing Process



Notes
1. *P represents the end product*
2. Subscripts 1 through 6 represent labor, material, and capital at the six product levels within the supply breakdown structure

breakdown structure. It means that risk is placed on risk, is placed on risk, is placed on risk, and so on. Hence, progress is carried out exponentially through the breakdown structure.

This simple concept now permits us to put the cost of capital into the risk "bubble," and shift it forward through the various levels as shown in Figure 7, which is a modification of Figure 6.

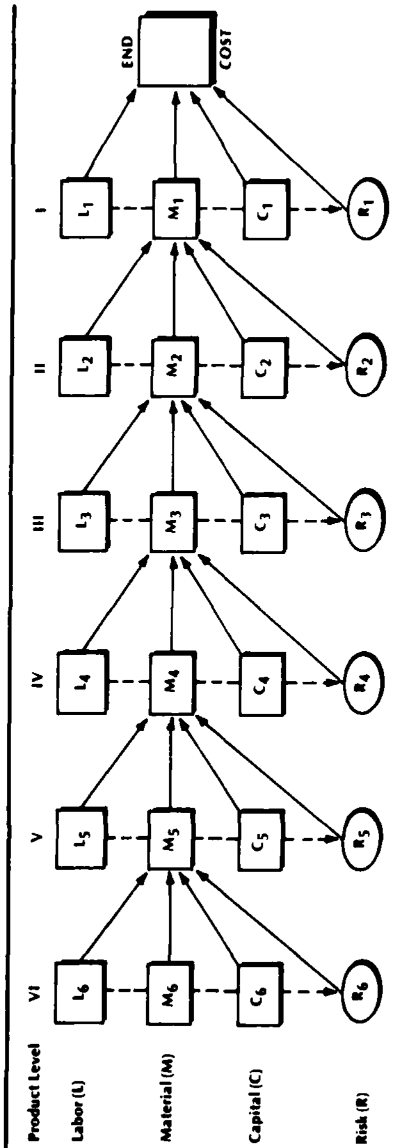
Let's assume that the risk factor is 10 percent. Conventionally, one may call this 10 percent profit or, as in our special case, a 10 percent interest rate on capital borrowed. The borrowed capital must be multiplied at Level VI by a risk factor of 1.1. If this risk enters Level V, and we assume 10 percent risk, the factor 1.1 must be multiplied again by 1.1. In short, the risk factor of 1.1 will grow as an exponential function to 1.1 to the sixth power, i.e., to 1.77 when it reaches Level I. Therefore, if we borrow $100 at Level VI at 10 percent interest, the end product will carry $177.

In this presentation, it is left up to the reader to define business risk. The terms risk, capital cost, and profit have been used in a generic and interchangeable way. However, it is believed that this simplification is justified because we are concerned with the concept only. We have chosen to disregard the mechanical implications in applying the concept to actual contracting.

Improving the Contractor's Cash Flow

There is a real need to improve the contractor's cash flow. Because the government does not allow interest to be used as an item of cost, cash flow and interest payments have to be carefully monitored by the government program

FIGURE 6
Risk Flow Through Supply Breakdown Structure



Note:
Subscripts 1 through 6 represent labor, material, capital, and risk at the six product levels within the supply breakdown structure

FIGURE 7
Flow Showing Shift of Risk Through Supply Breakdown Structure

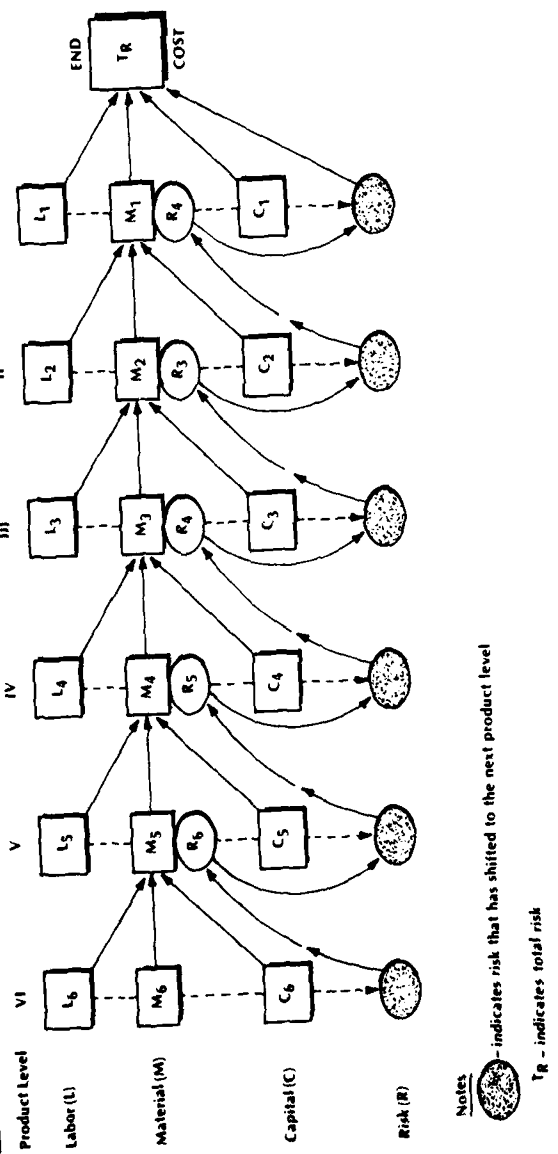
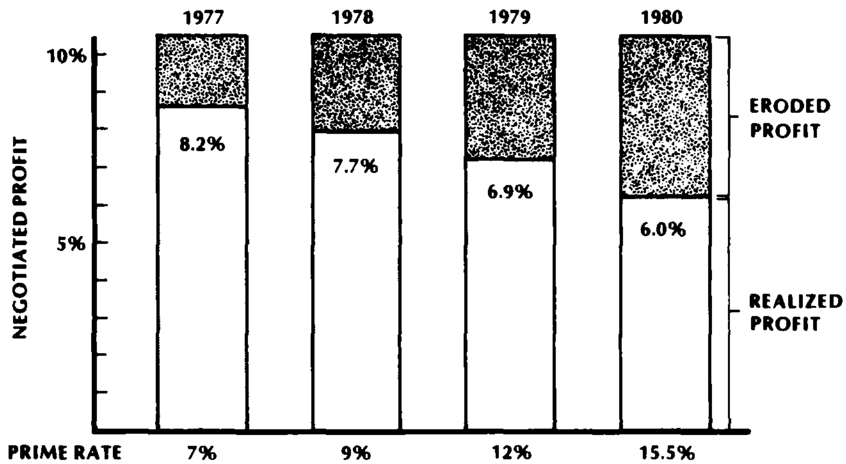


FIGURE 8
Effect of Interest Rate on Negotiated Profit



SOURCE: General Alton D. Slay, Commander, Air Force Systems Command, to House Committee on Armed Services, 13 November 1980.

manager. To encourage contractors to stay in defense business, consideration should be given to indexing progress payments to the prime interest rates. In the spring of 1980, the prime interest rates approached 20 percent. Although rates have dropped since that time, they are not expected to drop below the 10 percent level in the foreseeable future.

The current government position of not allowing interest rates to be an item of cost is untenable at a time when interest rates have moved into two digits. In a time of volatile interest rates, it may be appropriate to index interest rates as a part of the cost of contracting and of doing business with the government.

In private contracting, where price rather than cost is the basis for the contract, the contractor can compensate for the cost of borrowing money in the form of a high-budgeted profit. Because the profits of government contractors are restricted and the cost of borrowing money cannot be considered a contract item, many small contractors and suppliers will be "pushed" out of government business. It may force those who want to stay or must stay in the business, into dishonest accounting.

INTEREST EXPENSE

One of the major disincentives to contractor capital investment is the erosion of profit caused by not permitting interest expense to be an allowable cost on a defense system program. If interest charges must come out of profit, a contractor will not be motivated to borrow money to modernize or expand his facility or upgrade his manufacturing equipment. Figure 8 shows what happened when a contractor, who had negotiated a 10 percent profit, was forced to borrow money for capital investment each year from 1977 through 1980. It should be kept in mind that Figure 8 applies to an individual company and does not reveal the multiplier effect described previously.

The data in Figure 8 permits us to approximate the amount of borrowed capital. For example, if this contractor had a profit of 10 percent without borrowing capital, his business volume would have been $100 million and his profit would have been $10 million. If this contractor's profit dropped from $10 million to $6 million, $4 million would have to go into the payment of interest. If the $4 million had to cover a 20 percent interest rate, the borrowed amount would have had to have been $20 million, or one-fifth of the company's entire cash flow.

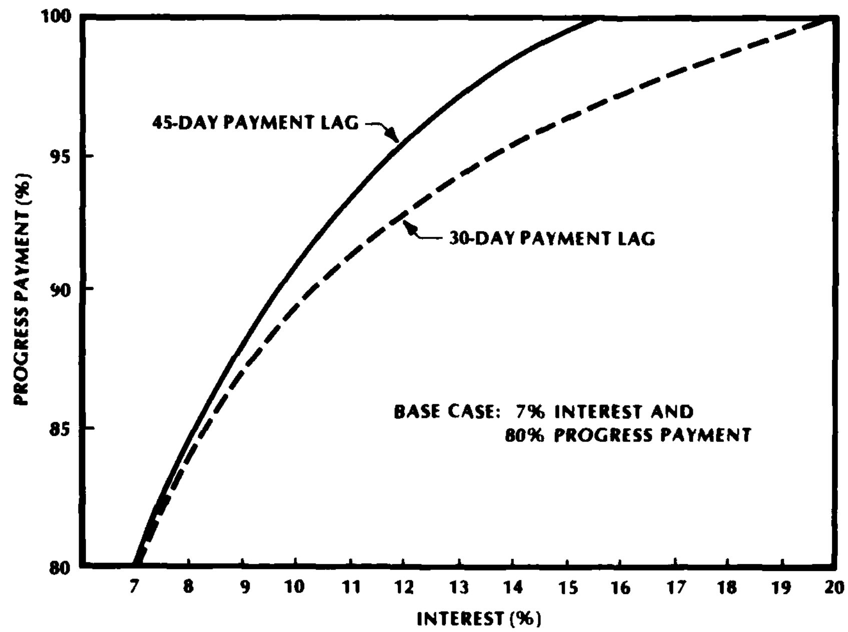
The rapidly changing prime rate identifies the problem, but it doesn't tell the whole story. Prime contractors normally pay from 1 to 3 percent above the prime rate to borrow money, principally because of the instability of the defense industry. When the prime rate reached 20 percent last year, it was almost triple the prime rate that prevailed in early 1977. The impact of these rates on subcontractor and suppliers—small business—can be substantial. Small businesses often have to borrow to survive. When the cost of borrowing becomes too high, the potential for failure increases.

STANDARD PROGRESS PAYMENTS

One way to compensate for loss in profit is to raise the standard progress payment. Progress payments have provided some protection to the government against the failure of a contractor to perform to contractual requirements. However, because of high inflation and interest rates, current progress payments have been placing an inordinate burden on defense contractors. Figure 9 illustrates how progress payment rates would have to increase as interest rates climb in order to maintain a contractor's profit.

The government's interests in a contract could be protected by a formula that would consider the risk of non-performance, interest rates, the cost of capital and contract profitability. Although the present progress payments limit provides a high degree of protection to the government, other aspects work against the government in improving productivity.

FIGURE 9
Progress Payment Rates Required to Maintain Profit at Various Interest Rates

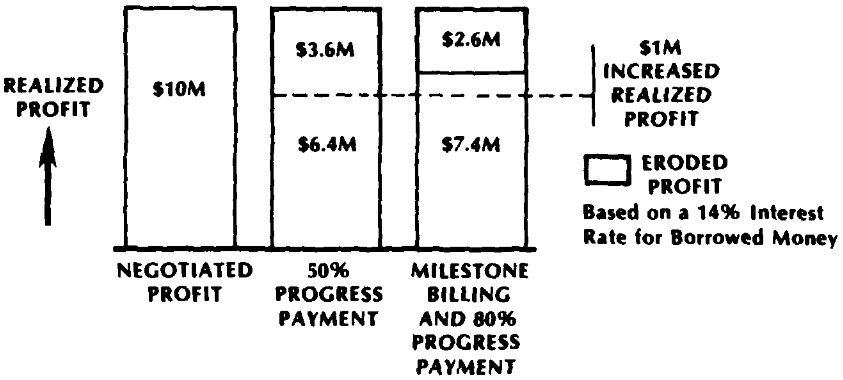


SOURCE: Defense Science Board

In March 1968, when the prime interest rate was only 6 percent, a progress payment limit of 80 percent for large business (prime contractors) and 85 percent for small business (subcontractors and suppliers) was established. Recently—March 1981—the Department of Defense approved a 5 percent increase in the standard progress payment limits, because withholding of progress payments tends to be counter productive for contracting in times of exploding interest rates. The new limits—85 percent and 90 percent—are set forth in a revision to Section 7 and Appendix E of the defense acquisition regulation (DAR).

Still more recently, the new administration announced a further increase in the percentage-of-cost progress payments. They will rise from 85 percent to 90 percent for prime contractors and from 90 percent to 95 percent for subcontractors and suppliers. In addition, authority will be given to contracting officers to

FIGURE 10
Effect of Progress Payments and Milestone Billings on Negotiated Profit



SOURCE: General Alton D. Slay, Commander, Air Force Systems Command, to House Committee on Armed Services, 13 November 1980.

use higher percentages if the new standard percentages will not provide the desired effect on a specific program, will not result in a contractor average-work-in-process inventory investment of no more than 5 percent.

MILESTONE BILLING

Another way to compensate for loss of profit is by milestone billing. How milestone billing can improve contractor profit over that available through standard progress payments is illustrated in Figure 10. Assume that $10 million was the negotiated profit on a $100 million defense system program. Also, assume the contractor received an 80 percent progress payment when the interest rate on borrowed money was 14 percent. The realized profit would have been $6.4 million. That means $3.6 million of the contractor's potential profit was lost. If the contractor had been permitted to submit billings at selected program milestones specified in the contract, the realized profit to the contractor might have increased by as much as $1 million. This would not solve the total problem the contractor had to face, but it would give him an added incentive to do business with the Department of Defense. One interesting thing to note is that the contractor could have obtained the additional profit at no additional cost to the taxpayer.

The Defense Acquisition Regulatory Council is proposing a modification to the current DAR policy regarding milestone billing arrangements. The proposed change to Appendix E-529 covers the purpose, criteria for use, contractual implementation, and approval criteria. The proposal was initiated by the Defense Contract Finance Committee to assure greater consistency in the application of milestone billing arrangements to individual contracts. The current DOD policy is that contractors should maintain an appropriate investment in their contract work-in-process inventories at all times. If the proposal is approved, contracting officers will have to establish an overall level of contract financing because contractors will still have to maintain an appropriate investment ir contract work-in-process inventory. Guidelines are provided in the proposed policy for determining the appropriate level of investment.

Application of the milestone billing procedure will result in periodic payments to the contractor within specified limitations and under the conditions set forth in the contract. Payments would be made upon verification of completion of distinct items of service or upon accomplishment of significant events.

The implementing regulation has been expanded to distinguish between milestone billing arrangements and progress payments. Milestone payments are payments in addition to progress payments and will not result in abolishment of progress payments. The value of a milestone is based upon an estimate of the cash to perform the milestone event. Profit is not to be included in the milestone value.

PAYMENT LAG

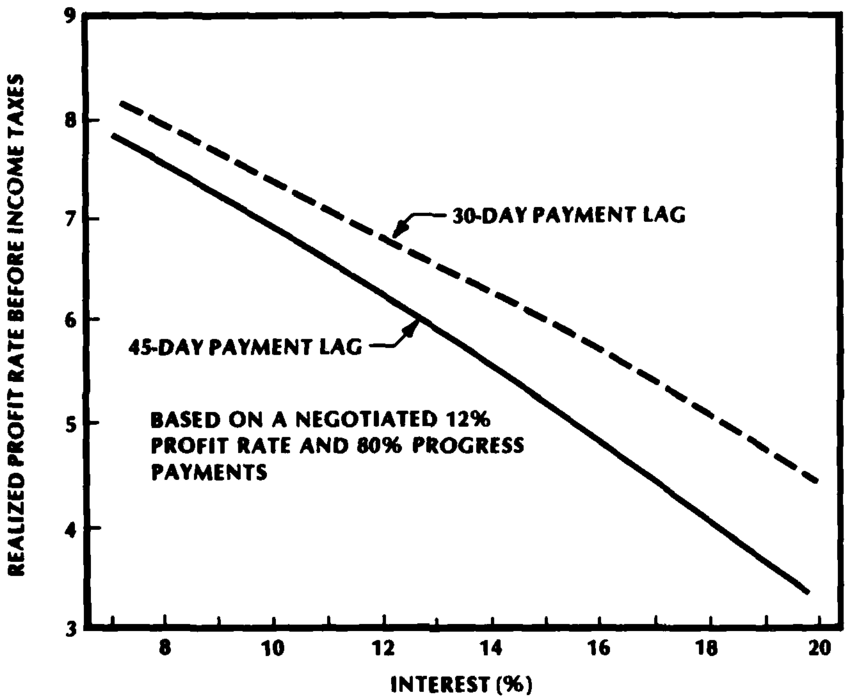
Payment lag is another factor to be considered in improving cash flow. There is considerable variance. Prime contractors generally get paid faster than subcontractors and suppliers. The difference in realized profit between a 30-day and a 45-day payment lag increases as the interest rate climbs. Figure 11 illustrates the inpact of borrowing and payment lag on realized profit. When the payment lag is shortened, it helps to protect the contractor's profit.

OTHER THOUGHTS ON PROFIT

Now let's consider the percent of investment per sales vs. return on sales and return on investment. For purposes of this discussion, investment will be defined as fixed capital at book value plus working capital. Figures 12 and 13 illustrate the profit impact of market strategies (PIMS)[4] from a data base containing in-depth information about 1,500 businesses (a business unit having specific consumers and competitors) within 250 corporations. The bar charts developed in late 1979

4. PIMS is a product of the Strategic Planning Institute, a non-profit organization located in Cambridge, Mass.

FIGURE 11
Realized Profit Rates at Various Interest Rates



SOURCE: Defense Science Board

show that as investment intensity rises, return of sales remains relatively flat, and return on investment declines.

In defense industry, a contractor's return on sales is usually not high. In 1980, the net return on sales after taxes for the average defense contractor was about 5 percent. This is only two and one-half times higher than it was in 1970. This profit is well below the average profit for all U.S. manufacturing. See Figure 14.

The profit on sales is important, but return on investment must also be considered. Although defense contractors receive a low return on sales, their return on investment is comparable to that of the rest of U.S. manufacturing organizations. This is because defense contractors have been able to minimize in-

FIGURE 12
Profit Impact of Market Strategy; "Gross" Margin Remains Relatively Unchanged as Investment Intensity Rises

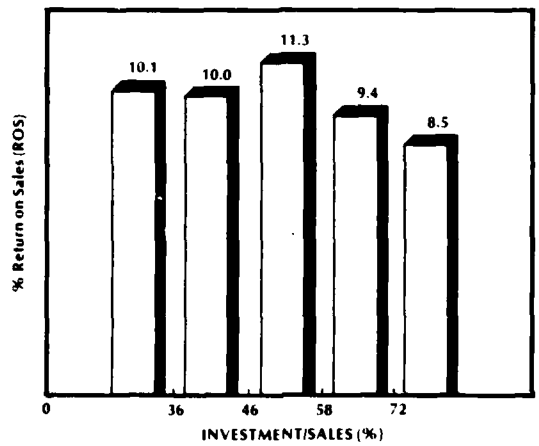


FIGURE 13
Profit Impact of Market Strategy:
ROI Declines as Investment Intensity Rises

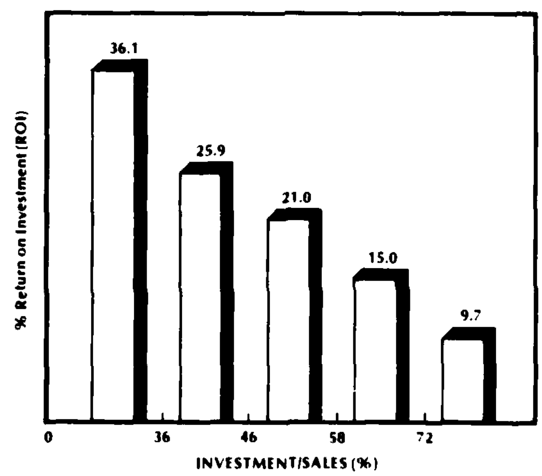
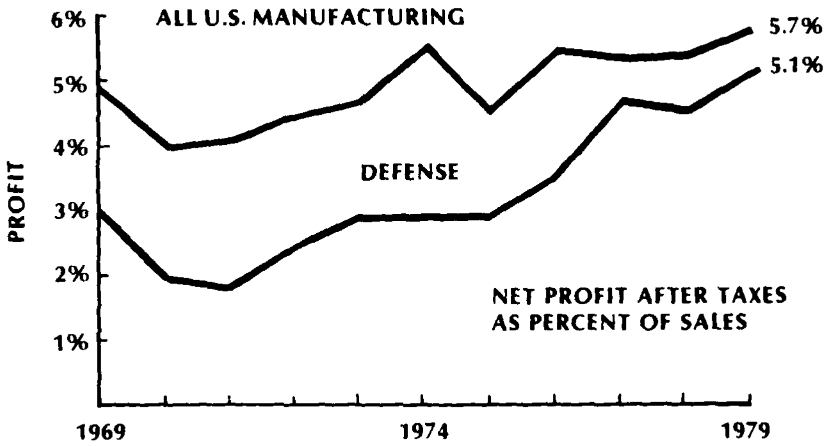


FIGURE 14
Profit for all U.S. Manufacturing Vs. Defense Only



SOURCE: Federal Trade Commission

vestments. Productivity is discouraged and, as a consequence, the rate of productivity growth in the United States was negative last year. This forebodes more problems in the future unless the trend is reversed.

In order to understand the problem of profit, let's consider it this way: Return on investment is a banker's concern, whereas return on sales is an entrepreneur's concern. Both are risk compensators. The risk covers all of the intangibles in conducting a business enterprise. When the profit is exhorbitantly high, say 40 percent, the differentiation between risk and profit becomes meaningless; however, when the profit is less than the usual business risk, it becomes ludicrous to talk about profit. In such a case, it would be appropriate to refer to it as "risk cost."

There are other problems associated with the high cost of borrowing money. Contractors try to keep their inventories at a minimum. Also, when contractors become reluctant to make heavy, up-front investments in critical materials, the lead times required to obtain these materials stretch out the length of a program and program costs increase.

Subcontractor and Supplier Problems Magnified

The financial impact caused by the situation just described is distressing for subcontractors and suppliers. They often have a need to borrow working capital; however, in most cases they are less able than the prime contractors to obtain non-bank financing. This is principally due to the size and/or financial condition of the subcontractors and suppliers. When the profits from DOD contracts are minimal, subcontractors and suppliers do not make capital investments. In addition, when profits are low many small and intermediate size companies find it beneficial to leave the defense marketplace. A large number have done so. This has not only eroded competition, it has reduced the ability of the United States to meet surge requirements for defense systems, should they ever become necessary.

Enhancing Contractor Financial Stability

One way to enhance the financial stability of defense industry is to include tailored economic price adjustment clauses in the contracts. These clauses remove one of the risks that neither the Defense Department nor the contractor has much ability to control. Another way is to provide protection from inflation in the contracts. This is particularly important in programs that have long full-scale development and production phases. To enhance the financial stability of subcontractors and suppliers in the "chain" on a given defense system program, the protective clauses should be passed along, beginning with the prime contractor.

Better depreciation rates should be offered. Defense contractors cannot recover the replacement costs of plants and equipment through the "useful life" depreciation allowances now available. There is a great disparity between the capital recovery tax laws in the United States and those of the competitive nations identified in Figure 1.

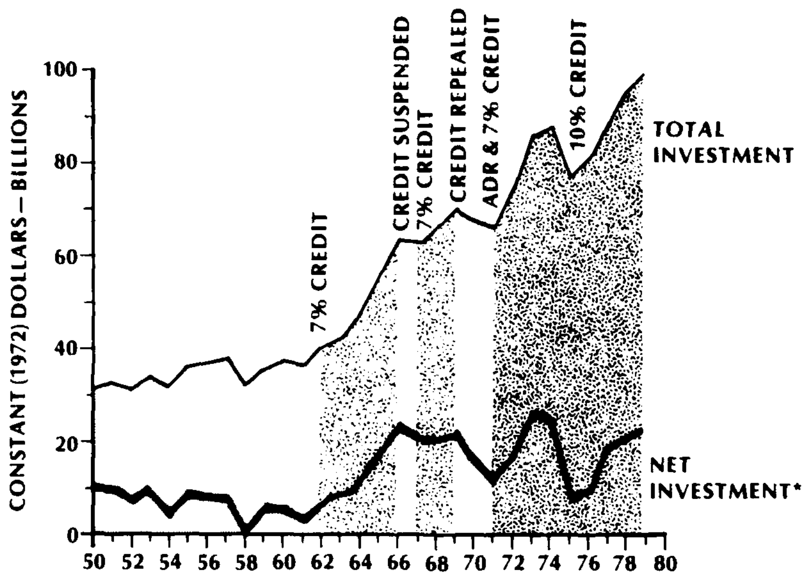
Finally, investment tax credits should be offered if the government wants to encourage the defense industry to make capital investments. The influence of tax incentives on capital equipment investment is displayed in Figure 15.

The need for contractors to make a reasonable profit must be clearly understood by the government. Offering the opportunity for a reasonable profit on defense systems contracts encourages capital investment by the contractors, their sub-contractors, and suppliers. Furthermore, it gives manufacturing companies an added incentive to enter and/or remain in the defense business.

Summary and Final Thoughts

Our federal government should modify its financing policies and practices as a partial solution to the present productivity problems, to encourage greater capital investment, and to encourage the flow of companies into, rather than out

FIGURE 15
Capital Equipment Investment
(Fixed, Non-residential, Producers of Durable Equipment)



*NET INVESTMENT IS NOT AVAILABLE FOR 1979.
SOURCE: BUREAU OF ECONOMIC ANALYSIS

of. defense business. Further, the government should assist the defense contractor's cash flow by indexing progress payments to prime interest rates and providing payments at milestones for partial completion of work.

The profit (risk compensation) permitted on a program should be higher when a contractor is not pre-financed, or when the contract does not include a tailored economic price adjustment clause. However, it is suggested that a tailored economic price adjustment clause be included in all contracts, regardless of the financing approach used.

Contractors should be encouraged to "flow down" the positive financial actions initiated by the government to their subcontractors and suppliers. On the other hand, the government should relax or rescind regulations that stifle production or productivity. There is no place for regulations whose costs exceed the benefits to be gained.

The government should change its current tax policy in order to encourage more capital investment by companies in defense industry. It is important for the government to provide aids to capital formation and recovery. This will help to ensure that the United States becomes more competitive with those practices now available in the other industralized nations.

The depreciation rates for capital equipment should be increased, capital formation for replacement costs should be tax free, and investment tax credits should be raised. Reduction in corporate tax rates could provide the needed incentive for defense contractors to increase their capital investments.

The time to take these actions is now. The future strength and surge capability of our defense industry may depend upon whether and how quickly the Department of Defense acts. ||

29 Evaluating the Impact of Quantity, Rate, and Competition

Larry W. Cox
Dr. Jacques S. Gansler

We, the authors, have been involved in acquisition research and analysis for several major DOD programs for some time. One recent research objective was the assessment of the costs and benefits of a single-source vs. a multiple-source production decision while allowing for variations (uncertainty) in both the total production quantity and the production rate. The majority of the research and analysis reported in this paper stemmed from that objective.

Drinnon and Gansler[1] reported that the introduction of competition in past DOD programs has resulted in immediate unit cost reductions and in accelerated unit cost improvement rates. We have further documented this phenomenon. One persistent problem in attempting to apply this characterization of the effect of the competitive pressure, as formulated, was that the magnitude of the observed cost reductions varied significantly. Furthermore, no consideration was given to the effect on production cost of variations in production rate.

We first reviewed the literature on other research into the effect of production rate on weapon system cost.[2] From this, an approach was hypothesized which incorporated all three factors (i.e., quantity, rate, and competition). We then compared the methodology to empirical data.[3] The results must be considered preliminary, but they are extremely promising.

Considerations pertaining to cost improvement curves, production rates, and competition are first discussed independently. Following this, the combined methodology we developed is explained, together with results of empirical data analysis. Finally, an illustrative example of the model's applicability to system acquisition decisions is presented.

Authors' note: We wish to acknowledge the contribution of B. A. Dembroski to some of the analysis reported in this paper. We also wish to acknowledge the contribution of J. W. Drinnon and J. R. Hiller to the preliminary work on the costs and benefits of competitive production sources expanded upon in this paper.

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1. J. S. Gansler and J. W. Drinnon, "Predicting the Costs and Benefits of Competitive Production Sources." Paper presented at the 9th Annual Acquisition Research Symposium, 1980.
2. Much of the results are summarized in Charles A. Smith, "Production Rate and Weapons System Cost: Research Review, Case Studies, and Planning Model." U.S. Army Procurement Research Office, Report No. APRO-80-05, November 1980.
3. By using a non-linear curve-fitting procedure, Appendix A elaborates.

Cost Improvement Curves

The concept of cost improvement curves originated as learning curves and was based on the observed increased efficiencies (learning) associated with any repetitive process. Two formulations of the phenomena ensued: one expressed as a decrease in *unit* cost as cumulative quantity increases; the other expressed as a decrease in *cumulative average* cost as cumulative quantity increases. The formulation expressed as a decrease in *unit* cost as cumulative quantity increases is the one used in this analysis. Some of the analysis contained in this paper focuses on dynamic aspects of cost improvement curves. Use of the cumulative average formulation would mask this aspect.

The terminology "cost improvement" curve is used because it is more appropriate for the majority of current applications than is the terminology "learning" curve. Although the original formulation was concerned solely with the learning aspect, current use incorporates the *collective* cost improvement resulting from a number of factors, of which traditional "learning" is only one.[4] Furthermore, the cost we are referring to is *cost to the government*, which corresponds to "price" in classical economics. Accordingly, the connotation throughout the remainder of this paper is on the collective cost improvement curve, where cost represents cost to the government.

Figure 1 displays a unit cost improvement curve in standard form. For a particular cost improvement curve, the greater the output, the lower is the unit production cost. A "90 percent" cost improvement curve is one in which a doubling of output drives unit cost down to 90 percent of its initial value; that is, a doubling of output leads to a 10 percent unit cost reduction. Similarly, for an "80 percent" cost improvement curve, a doubling of output causes a 20 percent reduction in unit cost.

Frequently, cost improvement curves are depicted in logarithmic form (the logarithm of unit cost as a function of the logarithm of cumulative quantity). This produces the linear relationship display in Figure 2. The steeper the slope of the cost improvement curve, the greater the cost reductions associated with increased quantity. In Figure 2, line AC predicts a cost of a_1 at quantity Q, while line AB

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4. As expressed by Bela Gold: ". . . most internal improvements . . . represent the results not of cumulative repetition of past practices, but of *changes* in: product designs; product mix; operating technology; *facilities and equipment; management, planning and control; materials quality; and labor* capabilities and incentives. And such changes result from the active exploration and development of superior alternatives to past practices by research personnel, design engineers, production specialists, and supervisory staff. This may also be termed 'learning'—if that term means nothing more than the summation of all improvements regardless of cause. . . ." From "Changing Perspectives on Size, Scale, and Returns: An Interpretive Survey," *Journal of Economic Literature*, Vol. XIX (March 1981), pp. 5-33.

FIGURE 1
Cost Improvement Curve in Standard Form

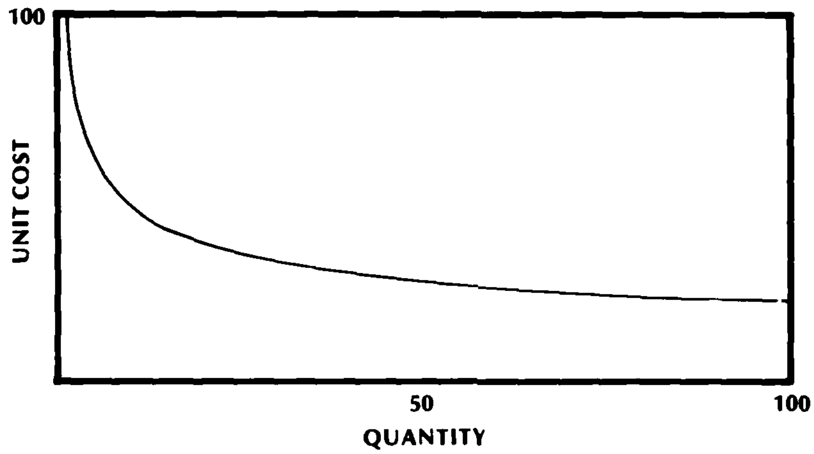


FIGURE 2
Cost Improvement Curve in Log-Linear Form

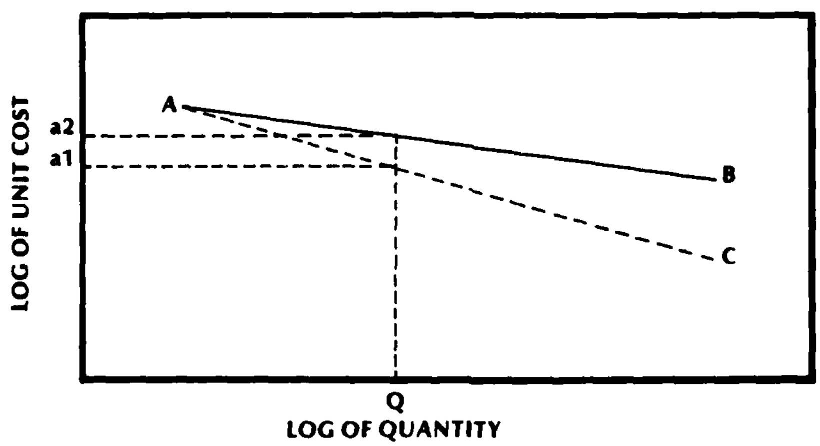
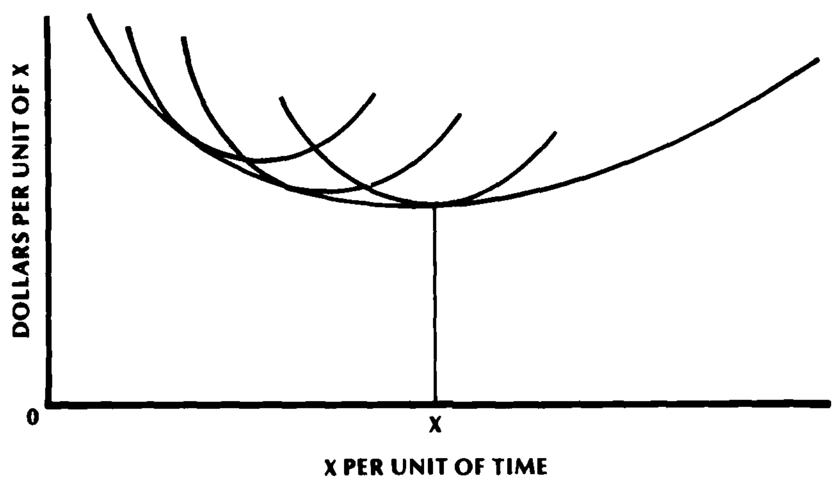


FIGURE 3
Economies and Diseconomies of Scale



predicts a higher cost of a_2 at Q. The starting point of the two curves is the same (point A). Only the slope (i.e., the rate of cost improvement) is different.

Although the log-linear representation is useful in analyzing cost improvement curves, it is important to remember that total production costs are represented by the physical area under the curve in standard form. The area under the log-linear curve is *not* a true representation of total production cost.

Production Rate Variations

Some of the prior research into the effect of production rate on unit cost has shown that in some instances, unit cost decreases with increases in production rate in a form virtually identical to that of cost improvement curves.[5] In other instances, prior research has demonstrated increases in unit cost with increases in

5. John C. Bemis, "A Model for Examining the Cost Implications of Production Rate," Department of Defense, Product Engineering Services Office, Defense Logistics Agency, Cameron Station, Alexandria, Va., and "Production Rate as an Affordability Issue," Paper presented at the 9th Annual Acquisition Research Symposium, 1980.

production rate.[6] *These results are not contradictory.* Economic theory says that there are both economies and diseconomies of scale, and that if one assumes that plant capacity is fixed, the effect of production rate on unit cost is best represented by a U-shaped curve (Figure 3). Unfortunately, economic theory provides very little guidance as to the most appropriate way to formulate this phenomenon mathematically.

The assumption of a U-shaped curve implies the existence of an optimal production rate; i.e., a production rate which minimizes the recurring cost associated with producing an item.[7]

Since research has demonstrated instances where increases in production rate result in decreases in unit cost in a manner identical to that observed with cost improvement curves, there is justification for assuming that the production rate curve takes this form up to the optimum production rate. Lacking justification for a preferred form above the optimum rate, the authors decided to assume that the curve was *symmetric* about the optimum rate. Thus, production costs are minimized when the production rate is equal to the optimum rate, R_0, and *increase in a uniform manner as one deviates* from the optimum value in either direction.

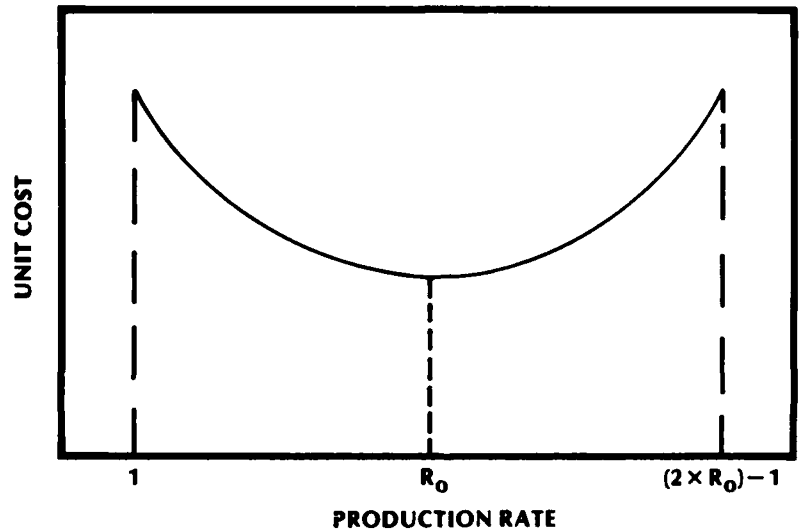
This formulation imposes the restriction that the maximum allowable production rate is $(2 \times R_0) - 1$. For a manufacturer to produce at a higher rate, the production capacity would have to be expanded, thus producing a new optimum rate. The chosen formulation is displayed in Figure 4.

Some may contend that a curve of one shape (possibly the one chosen) should be used as one increases production rate up to the optimum value, and that a curve of an entirely different shape be used as one increased production rate above the optimal value. Others may contend that the production rate curve should be rather steep at both extremely low and extremely high production rates and be rather flat in the middle. In reality, the effect of production rate on unit cost may take all of these forms plus others, depending on the peculiarities of individual production lines. However, with no justification to favor one formulation over the other, the symmetric curve chosen appears reasonable for the general case.

6. Much of the results of prior research is summarized in Smith (*loc cit*) and M. Zusman, N. Asher, E. Wetzler, *et al.*, "A Quantitative Examination of Cost Quantity Relationships, Competition During Procurement and Military Versus Commercial Prices for Three Types of Vehicles." Institute for Defense Analyses/Program Analysis Division. Study No. S-429. March 1974.

7. Typically, a manufacturer will arrive at this rate in an attempt to maximize his profits by considering his facility limitations, capital investment requirements, anticipated quantities and rates to be procured by the government, and requirements specified by the government to be able to procure at some level.

FIGURE 4
Effect of Production Rate on Unit Cost



Combined Representation

Combining the effect on recurring production cost of both cumulative quantity and production rate results in the formulation displayed in Figure 5. Thus, for a constant production rate, unit costs decrease in accordance with a standard cost improvement curve. Variations in production rate result in variations in the rate that unit costs decrease in relation to cumulative quantity. For example, moving from a relatively inefficient production rate to one near the optimum rate results in *more rapid* cost decreases than would have resulted from a standard cost improvement curve. Conversely, moving from an efficient production rate near the optimum to a less efficient rate some distance from the optimum results in a *reduced rate of cost improvement* from what would have resulted from a standard cost improvement curve, and could even result in *cost increases* if the most recent production rate is significantly different from the previous, more efficient rate.

Another way of representing this phenomenon is by a *family of cost improvement curves* where the relationship among them is a function of production rate.

FIGURE 5
Unit Cost as a Function of Both Quantity and Production Rate

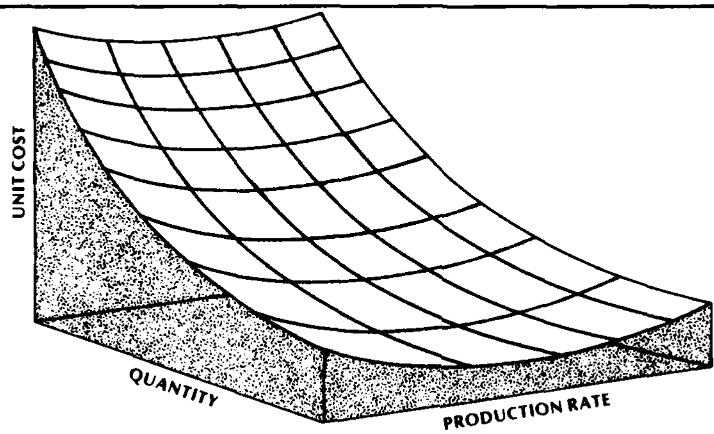


FIGURE 6
Family of Cost Improvement Curves Related By Production Rate (in Standard Form)

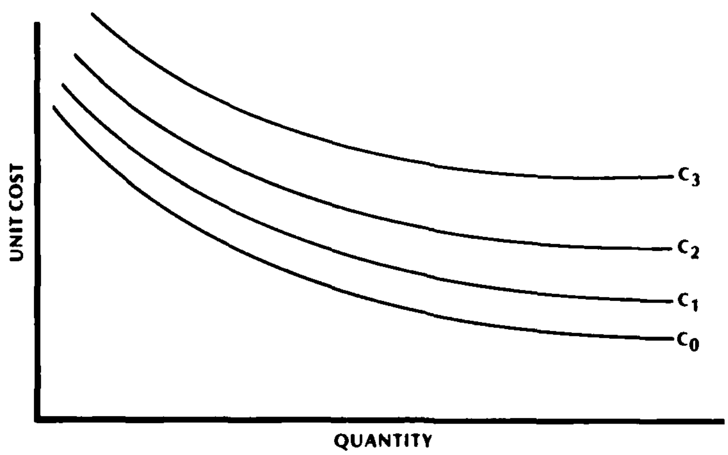
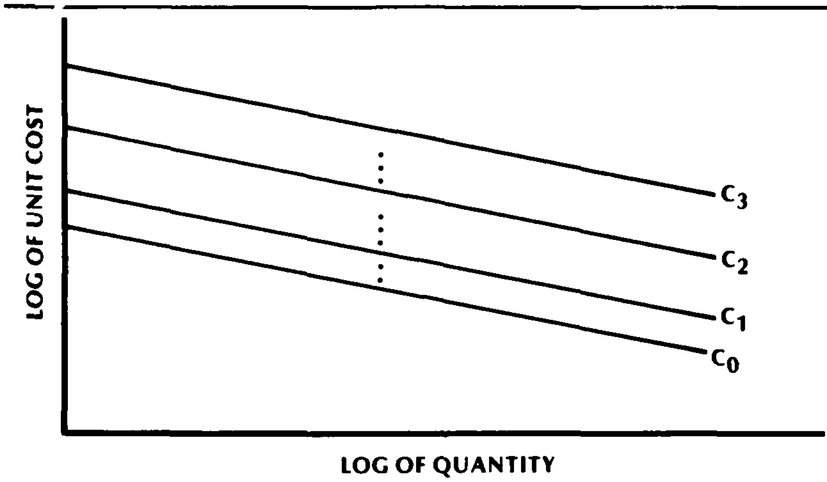


FIGURE 7
Family of Cost Improvement Curves Related By Production Rate (in Log-Linear Form)



This is displayed graphically in Figure 6. Curve C_0 represents the cost improvement curve a manufacturer would follow if he were constantly producing at his optimum, or most efficient, production rate. Curves C_1, C_2, and C_3 correspond to the cost improvement curves associated with producing at increasingly less efficient production rates. Thus, another way of characterizing the effect on unit cost of changes in production rate is by shifting from one cost improvement curve to another. Figure 7 displays this same family of cost improvement curves in log-linear form.

Frequently, the production of weapon systems and subsystems is characterized by a buildup (increase) in the production rate during the first few years, and is followed by a relatively stable production rate during the remainder of the production period. When plotting the average unit cost of each successive lot in an attempt to estimate the cost improvement curve of the producer, it is not uncommon to be confronted by a convex cost improvement curve (in log-linear form) such as that displayed in Figure 8. This phenomenon is sometimes referred to as a "deterioration of learning." The typical response is to use the cost improvement rate associated with the latter production lots (which also have more stable production rates) as a more accurate indicator of the firm's cost improvement rate.

FIGURE 8
Convex Cost Improvement Curve in Log-Linear Form

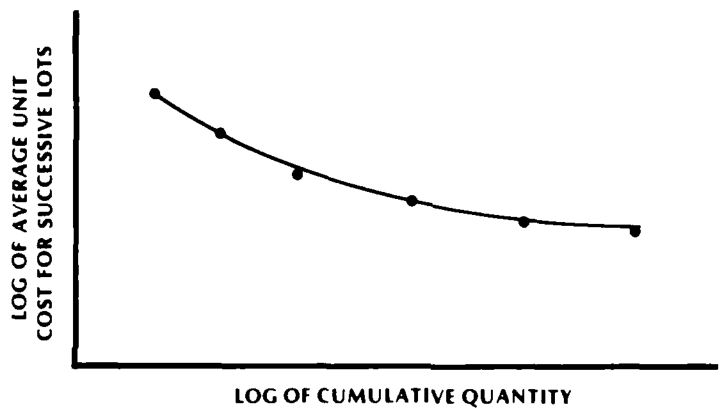
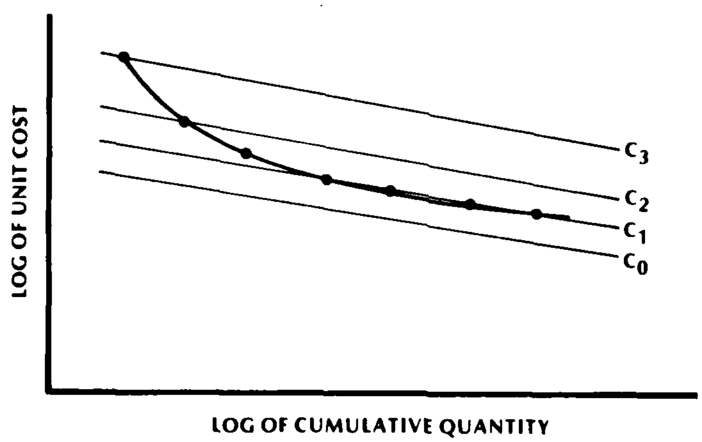


FIGURE 9
Overlay of the Convex Cost Improvement Curve and the Family of Cost Improvement Curves Related by Production Rate (in Log-Linear Form)



By overlaying Figure 8 with the family of cost improvement curves in Figure 7, another explanation of this phenomenon is readily apparent. In Figure 9, the average unit cost of the first lot is associated with cost improvement curve C_3, which corresponds to the relatively inefficient initial low production rate. The average unit cost of the second lot is associated with cost improvement curve C_2, which corresponds to a somewhat more efficient production rate attained by that time. The average unit costs of the third and successive lots are associated with cost improvement curve C_1 which corresponds to the more efficient production rate maintained throughout the remainder of the production period. Thus, the observed phenomenon of the convex-shaped cost improvement curve may well be attributable to the economies of scale common to many programs.

Clearly, a similar scenario can be developed to explain the *increase* in unit cost frequently observed when program stretchouts and budget reductions occur. By reducing the annual procurement quantity, the manufacturer is forced to produce at a lower, less efficient production rate. This corresponds to an *upward shift* to the cost improvement curve associated with the less efficient production rate, and thus, an increase in unit cost.

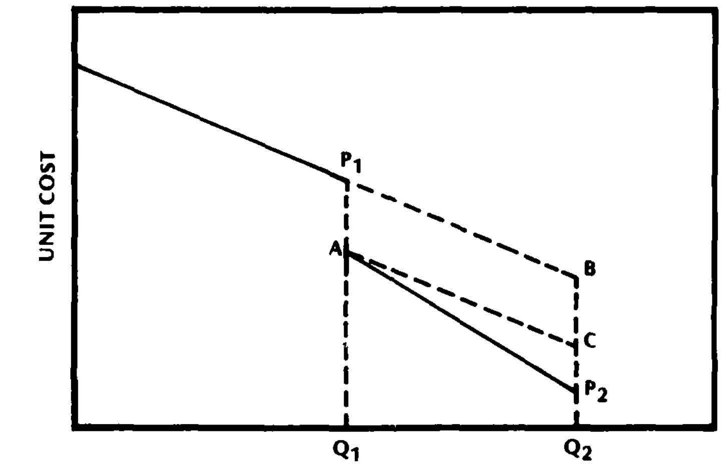
Competition

The conceptual approach we pursued with regard to competition is that competition constitutes an external force which causes firms to become more efficient and to reduce profits, thus reducing the cost to the government. By incorporating this conceptualization into the combined cost improvement curve and production rate methodology for estimating production costs, the impact of competition should be manifested by changes in the model parameters. Thus, the family of parameters associated with competitive procurements should differ significantly from the family of parameters associated with non-competitive procurements. In particular, analysis of programs where competition was introduced following a period of production on a non-competitive basis should provide direct evidence as to how the model parameters are affected by the force of competition.

Prior research by J. W. Drinnon and J. R. Hiller had hypothesized that the effect of competitive pressure was characterized by a *shift* and a *rotation* in the *collective* cost improvement curve of a firm (without considering production rate variations). They documented this effect in one instance. Figure 10 displays this concept on the log-linear form of the cost improvement curve.

In Figure 10 it is assumed the production was non-competitive for the first Q_1 units. At that point, competition from another firm was introduced. If we assume that the original firm won a competitive buy-out, the figure shows that the firm's price fell from P_1, prior to the introduction of competition, to P_2 at the end of the

FIGURE 10
Effects of Competition of Cost Improvement Curves (in Log-Linear Form)

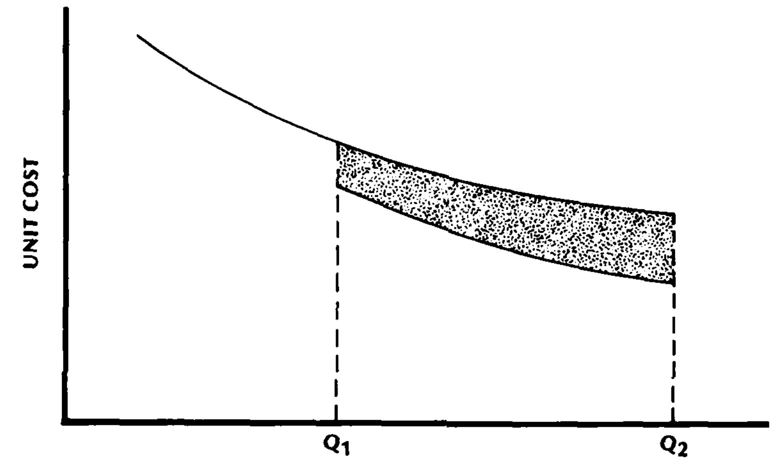


competition. Since the firm would have progressed along its cost improvement curve to point B without competitive pressure, the distance BP_2 is indicative of the gross savings due to competition.

The parallel downward shift from B to C was characterized by the combined result of reduced profit and cost reductions which the firm effected. The reduction from C to P_2 was characterized by the firm developing, under competition, a steeper cost improvement rate. The area P_1BP_2A is indicative of the total savings resulting from competition. Figure 11 displays this combined effect on the cost improvement curve in standard form. With the cost improvement curve presented in standard form, the shaded area is a true representation of cost savings due to competition.

We have incorporated this concept into the combined cost improvement curve and production rate methodology in two similar but unique ways. The first concerns the effect of competition on the parameters that characterize the original pr ducer's cost/quantity/rate relationships. The second concerns the nature of the parameters which characterize the second source's (competitor or soon-to-be competitor) cost/quantity/rate relationships.

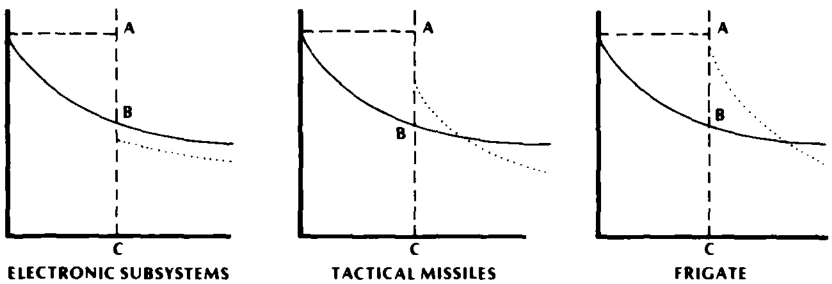
FIGURE 11
Effects of Competition on Cost Improvement Curves (in Standard Form)



For the original producer, we concluded that the effects of competition should be manifested solely in the cost improvement curve portion of the combined formulation rather than the production rate. Since the original producer's production line would be well established prior to the introduction of competition, and since the design of this production line essentially determines the nature of the cost/rate curve, it is logical to assume that the effect of production rate on unit cost would remain unchanged due to the introduction of competition.

If the second firm initiates production with the same cost improvement curve parameters and production rate curve paramaters as the original producer, then the second source would not be able to apply competitive pressure until his cumulative production quantity equaled the cumulative production quantity of the original producer. Since learning quantities and directed buys for a second source are usually small when compared to the production quantities of the original firm, the model parameters for the second firm must reflect the ability of the second source to reach cost parity rapidly with the original producer. This may take the form of a lower first unit cost, a steeper cost improvement curve, a steeper production rate curve, or various combinations of all three aspects. Whatever the form, the *combined effect must be present*. Historical data analysis should manifest the particular form(s).

FIGURE 12
Comparison of Collective Cost Improvement Curves of First and Second Sources



Analysis of Historical Data

The authors have collected a sizeable data base on the production histories of various weapon systems and subsystems; some for equipment procured strictly on a non-competitive basis, some for equipment procured strictly on a competitive basis, and some where competition was introduced following a period of production on a non-competitive basis. Analysis to date had concentrated on the latter group. Within this group, a large percentage of the data, while useful, is unsuitable for detailed analysis. Typical inadequacies include missing data points, production breaks, and insufficient length of the production period. While the quantity of data analyzed to date is inadequate to demonstrate statistical veracity, the authors have succeeded in analyzing sufficient data to demonstrate that the methodology is reasonable and to indicate the nature of the model's parameters under varying situations.

During the course of the data analysis, we also developed, as a research tool, computerized procedures for obtaining a "best-fit" of the model to empirical data. In our opinion, the procedures developed are an improvement over the procedures traditionally employed. Appendix A addresses the *reason* for developing these techniques and provides a brief description of the methodology.

BEHAVIOR OF THE SECOND SOURCE

We have compared the *collective* cost improvement curves (without separating the effect of production rate) of the first and second source on eight military electronics programs, five tactical missile programs, and one guided missile frigate. The results are displayed in Figure 12.

The guided missile frigate was the most expensive and most complex item for which the authors acquired data. The cost of the first frigate produced by the second source exceeded the cost of the first frigate produced by the initial source by approximately 9 percent. However, the slope of the collective cost improvement curve of the second source was approximately 4 percent steeper than that of the first source.

Tactical missiles are typically both less expensive and less complex than a guided-missile frigate, but more expensive and more complex than military electronics subsystems. For these five missile cases, the first unit cost of the second source was, on the average, 25 percent less than the first unit cost of the original producer. However, this was still greater than the unit cost the first source had progressed to at that time. The slope of the cost improvement curve of the second source was, on the average, 5 percent steeper than that of the original producer.

For the military electronics subsystems, competition was conducted with *no learning quantities or educational buys for the second source*. Furthermore, in the majority of the cases, *the second source won the competition* and began production at a lower cost than the first producer had progressed to at this time. The data did not permit calculations of actual cost improvement curve parameters for the second source; however, the cost reductions were clearly apparent.

Viewed collectively, the data clearly suggest a relationship between the cost and complexity of a system and the nature of the cost improvement curve of a second source. For less costly and complex systems, a second source can be competitive from the outset; as cost and complexity increase, more time is required for a second source to be competitive. Furthermore, in *all cases where there was sufficient data to permit analysis, the slope of the collective cost improvement curve of the second source was steeper than that of the original producer.*

COMPARISON WITH EMPIRICAL DATA

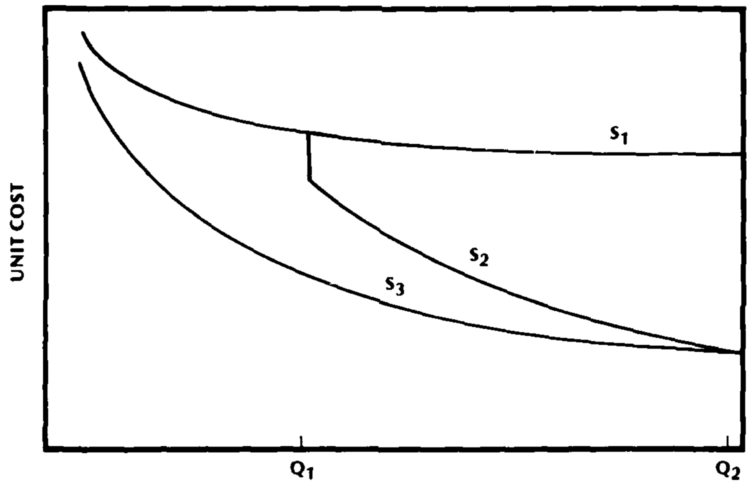
The authors have obtained "best-fit" estimates of all model parameters for five sets of production history data from tactical missile programs. In all cases, the model fits the data extremely well. The difference between actual costs and costs estimated by the model with the best-fit parameters are typically less than one percent for the average unit cost of individual lots, and less than 0.2 percent for total production costs. The parameters obtained, together with other relevant factors, are presented in Table I.

These five cases clearly demonstrate the shift and rotations of the cost improvement curve portion of the combined formulation for the original producer when competition is introduced. Furthermore, they demonstrate that the magnitude of the shift and rotation can vary significantly. However, there is a readily apparent high correlation between the magnitude of the shift and rotation

TABLE I
Model Parameters for Tactical Missile Data

DATA	FIRST UNIT COST	SOLE SOURCE COST IMPROVEMENT CURVE SLOPE	PRODUCTION RATE CURVE SLOPE	OPTIMUM LOT SIZE	COMPETITIVE		QUANTITY PRODUCED PRIOR TO COMPETITION	"OPTIMAL" COST IMPROVEMENT CURVE SLOPE
					SHIFT	ROTATION		
SPARROW (1ST SOURCE)	415,336	.846	.985	1,250	4.3%	8.1%	1,625	.833
SPARROW (2ND SOURCE)	450,186	.874	.923	1,250	−0.4%	13.2%	505	.849
BULLPUP	53,416	.823	1.004	7,950	12.6%	11.8%	7,520	.800
TOW	5,297	.991	1.007	6,000	15.5%	35.0%	15,750	.926
SIDEWINDER	16,021	1.047	.819	4,150	16.3%	34.7%	11,285	.982

FIGURE 13
Relationship Between Competitive and Non-Competitive Cost Improvement Curves (with Variations Due to Production Rate Removed)



and the quantity produced prior to the introduction of competition. That is, the *larger the quantity procured on a non-competitive basis, the greater the magnitude of the shift and rotation.*

Figure 13 displays a theoretical framework which accounts for this phenomenon. Curve S_1 depicts the cost improvement curve portion of the combined formulation one might observe from a company producing in a non-competitive environment. Curve S_2 depicts the shift and rotation of the cost improvement curve observed when competition is introduced after Q_1 units have been produced. As the results from the five tactical missile cases demonstrate, the magnitude of this shift and rotation tends to increase as the prior production quantity increases. Assume curve S_3 depicts an "optimal" or "best" cost improvement curve portion of the combined formulation one might observe if the manufacturer were under continuous competitive pressure from the outset. The distance between curve S_1 and curve S_3 increases with increasing quantity. Consequently, the potential for cost reductions from the non-competitive position increases the larger the quantity produced prior to the introduction of competition.

With this theoretical framework, the observed shift and rotation of the original producer's cost improvement curve resulting from competitive pressure can be characterized as "making up" for earlier cost improvements which were possible, but were unrealized due to the absence of competitive pressure.

If one assumes that the shifted and rotated cost improvement curve (S_2) in Figure 13 achieves cost parity with the "best" curve (S_3) at the end of the production run, then it is possible to calculate parameters for the "optimal" curve. The last column in Table I is the slope of this "optimal" curve under the assumption that the first unit cost for the "optimal" curve is the same as the first unit cost for the non-competitive curve. In other words, if one assumes that the only change to the set of model parameters pertaining to the non-competitive portion of the data is the slope of the cost improvement curve, what slope will allow the manufacturer to follow a continuous cost improvement curve from the outset (i.e., from unit number one) and still achieve the observed competitive unit costs (i.e., those observed following a shift and rotation of the non-competitive curve)? This is the slope that appears in the last column in Table I.

The authors have also obtained "best fit" estimates of model parameters for eight sets of production history data for military electronics subsystems. The electronics data was insufficient to calculate a complete set of model parameters both before and after the introduction of competition; however, the cases were sufficient to determine a complete set of model parameters prior to the introduction of competition, and to calculate the corresponding "optimal" curve the producers would have had to have followed from the outset to achieve the observed competitive costs (assuming first unit costs were unchanged). The results of this analysis are displayed in Table II.

The authors then applied linear regression with the slope of the non-competitive cost improvement curve portion of the combined formulation as the independent variable and the slope of the "optimal" competitive cost improvement curve portion of the combined formulation as the dependent variable. This yields the results in Table III which are displayed graphically in Figure 14. There is clearly a statistically significant relationship.

In other words, by combining the cost improvement curve and production rate methodology with a theoretical framework describing the effect of competitive pressure on the model parameters, the authors have discovered a statistically significant relationship between model parameters representative of a non-competitive environment and those representative of an "optimal" competitive environment. Thus, the model has potential application in demonstrating the possible interactions and changes in cost to the government surrounding the use of competitive production sources for weapon systems procurement.

TABLE II
Model Parameters for Military Electronics Data

DATA SOURCE	FIRST UNIT COST	SOLE SOURCE COST-IMP CURVE SLOPE	RATE CURVE SLOPE	OPTIMUM LOT SIZE	"OPTIMUM" CURVE SLOPE
AERNO 60-6402 ELECTRONIC CONTROL AMPLIFIER	16,876	.992	.960	140	.848
TD-204 CABLE COMBINER	36,143	.880	.947	$\geq$ 633	.832
TD-660 MULTIPLEXER	429,970	.754	.888	$\geq$ 1,425	.729
TD-202 RADIO COMBINER	31,293	.874	.946	$\geq$ 2,635	.816
MD-522 MODULATOR-DEMODULATOR	20,786	.860	.975	950	.806
ASW-27 AVIONICS	244,790	.883	.877	$\geq$ 100	.846
AN/APM-123 TRANSPONDER TEST UNIT	14,528	.957	.967	325	.882
TD-352 MULTIPLEXER	13,181	.967	1.015	$\geq$ 2,358	.891

TABLE III
Correlation Between Non-Competitive and "Optimal" Competitive Cost Improvement Curve Slopes

DATA	SAMPLE SIZE	CORRELATION COEFFICIENT	T-VALUE/ LEVEL OF SIGNIFICANCE	F-VALUE/ LEVEL OF SIGNIFICANCE
TACTICAL MISSILES	5	.995	16.9/.001	285/.05
MILITARY ELECTRONICS	8	.986	14.4/.001	207/.05
BOTH	13	.972	13.8/.001	189/.05

FIGURE 14
Correlation Between Non-Competitive and "Optimal" Competitive Cost Improvement Curve Slopes

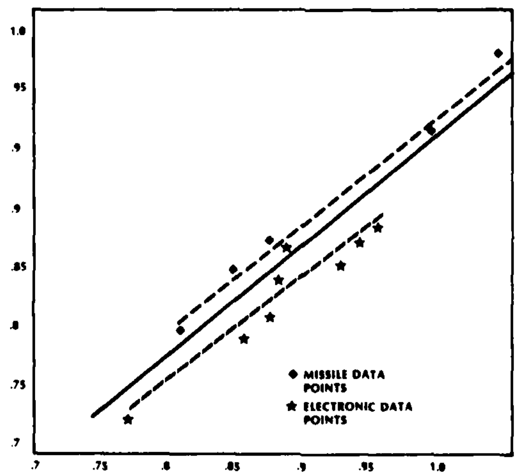


TABLE IV
Variability in Yearly Production Quantities

	COMPRESSED SCHEDULE	PLANNED SCHEDULE	STRETCHED SCHEDULE
LOW RANGE	2300	1600	1300
PLANNED RANGE	3200	2400	1800
HIGH RANGE	4600	3400	2700

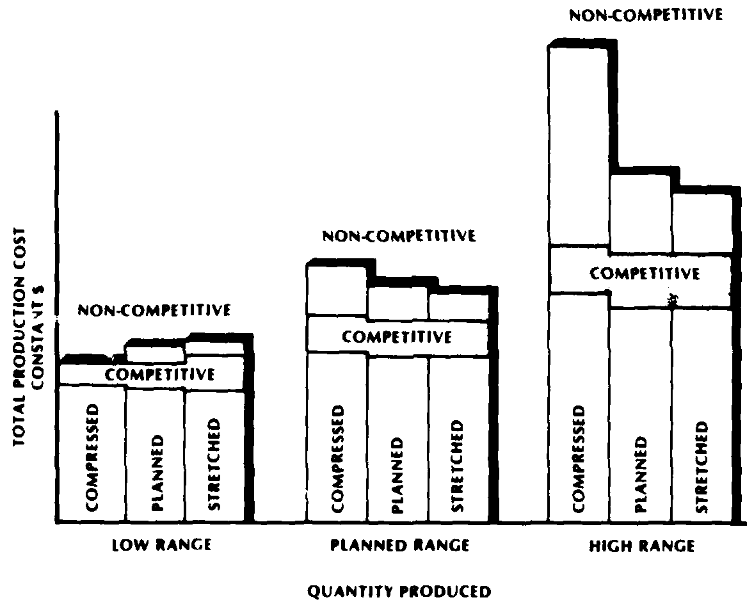
Applying the Methodology

Planning for the production of weapons systems or subsystems frequently involves the consideration of many alternatives. Typically, a baseline production plan is developed. Consider a hypothetical system where the baseline plan is for a gradual build-up in production rate until a yearly rate of 2,400 units (200 per month) is attained. This rate is to be sustained over several years until the total required quantity is produced. Given this baseline plan, a manufacturer would likely design his production line to attain maximum efficiency (and, in all likelihood, maximum profits) at the sustained rate of 2,400 units per year.

However, for this hypothetical program, there is a distinct possibility that requirements (and/or funding changes) could necessitate either a more compressed schedule (i.e., producing the total requirements in a shorter time period), or a stretched-out schedule (i.e., producing the total requirements over a long period of time). Furthermore, the requirements are sufficiently soft that the total quantity could be either signigicantly smaller than the baseline plan or significantly larger than the baseline plan. (Recent history points to smaller quantities over a longer period).

As the program schedule becomes either compressed or stretched, and as total quantities increase or decrease, the impact on yearly production quantities could approximate that depicted in Table IV. If the manufacturer did optimize his production line for 2,400 units per year, clearly some of these rates result in large inefficiencies. If the program office is also considering awarding learning quantities to a second firm with the intent of introducing later competition, the uncertainties are further compounded.

FIGURE 15
Results from Illustrative Example



Under the scenario just described, we have created an illustrative example of the applicability of the combined cost improvement curve, production rate, and competition model to production planning using representative parameters observed during the data analysis.

Figure 15 displays relative total production costs one could reasonably expect under the varying alternatives. The top of each bar corresponds to the non-competitive cost for each scenario. The shaded region corresponds to feasible ranges for the costs when a second source is given early learning quantities and then introduced as a competitor approximately halfway through the production period. The bottom of the shaded region (i.e., the lowest cost) corresponds to the assumption that the magnitude of the shift and rotation of the cost improvement curve resulting from competitive pressure is approximately that observed from the data analysis. The top of the shaded region (i.e., the highest cost) corresponds to the assumption that the magnitude of the influence of competition is one-half that observed from the data analysis.

The extremely high non-competitive costs associated with the compressed schedule with the high production quantities is, in all likelihood, a worst-case representation of this scenario. It results from the sole-source manufacturer producing at a sustained annual rate of 4,600 units with his optimal annual rate set at 2,400 units. This causes him to be far up the right-hand side of the U-shaped production rate curve. Should this situation develop, the manufacturer, in all likelihood, would expand his production capabilities and increase his efficiency at the higher production rate.

It is worth emphasizing that in this example, competition produces cost savings, even under rather pessimistic assumptions and low production quantities. As production quantities and rates increase, potential savings from a multiple-source approach increase accordingly.

A program manager involved in production planning is frequently faced with a high degree of uncertainty surrounding both the timing and the quantity of the requirements for his particular system or subsystem. He operates in an environment which stresses competition, efficient delivery rates, and economies of scale. Furthermore, his funding estimates are made 2 to 5 years in advance. Given this scenario, it is advantageous for the program manager to consider a wide range of feasible alternatives in order to structure a production plan adaptable to changing conditions.

The methodology presented in this paper provides a means to evaluate many of these alternatives. Specific applications of the methodology should be tailored to the unique system or subsystem and supported by appropriate data analysis.

Summary

By drawing heavily on key results from prior research, we have formulated a methodology incorporating the interrelationships of cost improvement curves, production rates, and competition on the production costs of weapon systems and subsystems. The methodology has been evaluated against empirical data using improved data analysis techniques. While insufficient data have been analyzed to demonstrate statistical veracity, the results from data analysis do demonstrate that the methodology is reasonable, and also sheds new insight into the impact of competitive pressure on production costs, i.e., that competition may provide the necessary incentive for a manufacturer to achieve an "optimal" cost improvement curve. Finally, an illustrative example is included which indicates potential uses for the methodology.

Appendix A
Data Analysis Methodology

In the prior research reviewed by the authors concerned with comparing a cost improvement curve or production rate model to empirical data, the log-linear form of the equations were used. In this formulation, "lot midpoints" (the unit whose cost equals the average unit cost for the lot) were estimated, and multiple linear regression was then used to estimate parameters.

There are several methodologies commonly employed to estimate lot midpoints. These methodologies perform adequately most of the time when applied solely to a cost improvement curve, although at times errors can be introduced (lot midpoints are in reality a function of the cost improvement curve slope). However, when these methodologies are applied to a formulation combining cost improvement curves with production rate, they frequently provide unreliable estimates. The use of these estimates, combined with the differences between obtaining a least-squares solution to the log-linear form of the model as opposed to the exponential form, can produce dramatic differences in the results.

Perhaps the following simple example will help clarify the situation:

Lot Number	Lot Size	Avg. Unit Cost	Estimated Lot Midpoint*
1	50	38.02	17.5
2	500	17.17	300
3	1,000	11.72	1,050

* Estimates were obtained using the commonly used method:

$$\text{First lot midpoint} = \frac{\text{first lot quantity} + 1}{3} + 0.5$$

Subsequent lot midpoints = 1/2(lot quantity) + total of all preceding lots.

We will assume that lot size is a reasonable proxy for production rate, and proceed to estimate the parameters so that we obtain a least-squares solution to the log-linear form of the model ($\log Z = \log A + B \log X + C \log Y$). The following equations result.

$$\log 38.02 = \log A + B \log 17.5 + C \log 50$$
$$\log 17.17 = \log A + B \log 300 + C \log 500$$
$$\log 11.72 = \log A + B \log 1050 + C \log 1000$$

The least-squares solution to this set of equations yields the following:

$$A = 72.5 \qquad (\log A = 1.8603)$$

$$B = -0.35878 \qquad P_1 = 0.78 \text{ where } B = \frac{\log P_1}{\log 2}$$

$$C = 0.097517 \qquad P_2 = 1.07 \text{ where } C = \frac{\log P_2}{\log 2}$$

These are *not* the correct parameters for this example. This hypothetical example was generated by using the exponential form of the model, by using lot size as a proxy for production rate, and by using the following parameters.

Actual Values

$$A = 100$$

$$B = -0.2345 \qquad P_1 = 0.85 \text{ where } B = \frac{\log P_1}{\log 2}$$

$$C = 0.0740 \qquad P_2 = 0.95 \text{ where } C = \frac{\log P_2}{\log 2}$$

Since these actual values for A, B, and C are significantly different from those obtained by estimating log midpoints and obtaining a least-squares solution to the log-linear form of the equation, there is clearly something inadequate in using that approach. In this case, the error is in estimating the lot midpoints, as the following illustrates:

Lot Number	Estimated Lot Midpoint	Actual Lot Midpoint
1	17.5	18
2	300	258
3	1,050	1,057

To obtain a least-squares estimate of the parameters from the equation in exponential form, it is much more complicated, both mathematically and computationally, but it is not an impossible task. We have developed a computer program to do this, and for this hypothetical example, the process yields the identical parameters used to generate the example.

The methodology involves finding the solution to a set of non-linear equations. The solution to the log-linear formulation is used as the initial starting point and successive iterations are based on a generalization of Newton's method for finding the roots of a non-linear function. The program was coded in APL (a programming language) on an IBM 5110.

The program was developed as a research tool and requires human interaction for its successful operation. The purpose for developing the computerized procedure was to analyze empirical data in such a way that the results obtained were not influenced by the procedure (which can result when using linear regression on the log-linear transformation).

Department of Defense Acquisition Improvement Program

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Colonel G. Dana Brabson, USAF

We stand at a singular point in time. We have a unique opportunity to significantly improve the defense of our nation. It appears that there is the prevailing view among the American people that a larger percentage of our gross national product should be spent on defense. At the same time, we have been strongly alerted that we must be good stewards of our resources. In a fiscal year in which the DOD budget is scheduled to grow substantially almost all other federal agencies will experience substantial budgetary cuts. With these gigantic, countervailing forces at work, the window available to us to make major advances in our preparedness may be very short—possibly as short as 1 or 2 years.

In full appreciation of this environment and its implications, Deputy Secretary of Defense Frank C. Carlucci took action. On 2 March 1981, he chartered five working groups—involving all of the services and inviting inputs from industry—to make recommendations with regard to improving the acquisition process. The report of the working groups was delivered on 31 March 1981. Mr. Carlucci's response to the report is best stated in his own words: "I have discussed the report with the Steering Group, the Joint Chiefs of Staff, the Service Secretaries, and the Under Secretaries and selected Assistant Secretaries of Defense. Based on the report and those meetings, the Secretary and I have decided to make major changes both in acquisition philosophy and the acquisition process itself." On 30 April 1981, Mr. Carlucci issued his decisions and identified 31 actions for implementation by DOD. Mr. Carlucci signed one more action on 27 July 1981, yielding the current total of 32 (see Figure 1). The actions became effective on the dates they were signed.

The purpose of this paper is to provide the program manager with a working knowledge of these 32 actions to improve defense acquisition. At the outset, it should be noted that while these actions compose a well-reasoned set, they are by no means all inclusive; they address many of the crucial acquisition management problems, but leave many important problems unsolved. It is at this point that the program manager can play a particularly vital role by building on the 32 actions, to point the way to many other actions to improve the acquisition process.

The 32 acquisition improvement actions fall into several classes. Many of the actions have already been implemented and the effects are already being felt in the field; others require high-level (e.g. congressional) approval or acquiescence.

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FIGURE 1
Acquisition Improvement Actions

1. Reaffirm Acquisition Management Principles
2. Increase Use of Preplanned Product Improvement
3. Implement Multiyear Procurement
4. Increase Program Stability
5. Encourage Capital Investment to Enhance Productivity
6. Budget to Most Likely Costs
7. Use Economical Production Rates
8. Assure Appropriate Contract Type
9. Improve System Support and Readiness
10. Reduce Administrative Costs and Time
11. Budget for Technological Risk
12. Provide Front-End Funding for Test Hardware
13. Reduce Governmental Legislation Related to Acquisition
14. Reduce Number of DOD Directives
15. Enhance Funding Flexibility
16. Provide Contractor Incentives to Improve Reliability and Support
17. Decrease DSARC Briefing and Data Requirements
18. Budget for Inflation
19. Forecast Business Base Conditions
20. Improve Source Selection Process
21. Develop and Use Standard Operation and Support Systems
22. Provide More Appropriate Design-to-Cost Goals
23. Implement Acquisition Process Decisions
24. Reduce DSARC Milestones
25. Submit MENs with Service POM
26. Revise DSARC Membership
27. Retain USDRE as Defense Acquisition Executive
28. Raise Dollar Thresholds for DSARC Review
29. Integrate DSARC and PPBS Process
30. Increase PM Visibility of Support Resources
31. Improve Reliability and Support
32. Increase Competition

Ultimately, the program manager will benefit from these actions, but meanwhile, there is nothing he can do except respond to requests for data and supporting evidence.

By far the most important actions, however, are those which require decisions on the part of the program manager. These decisions will be based largely on the answers to two questions: (1) Is this action applicable to my program? and (2) What measures can or should I take in response to this action?

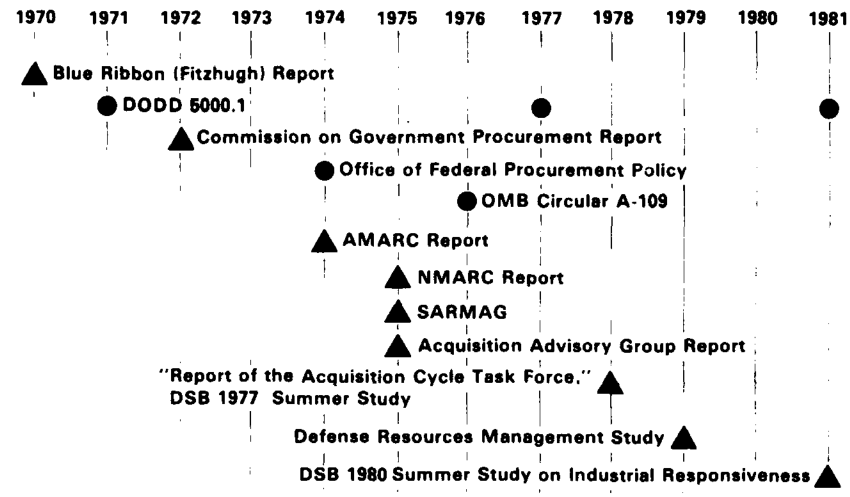
Before proceeding any further, it is appropriate to note that we have seen many of these words before. Accordingly, we have every right to ask, "So what is different this time?" The difference is this: Mr. Carlucci has also heard the rhetoric many times, and is determined to replace rhetoric with actions. The Department of Defense is prepared, perhaps more than ever before, to *demonstrate by its actions* its commitment to the principles of effective systems management. Indeed, the DOD has already demonstrated its commitment by a series of far-reaching measures. And the activity associated with implementing the remaining actions can best be described as "intense." The current revision of DOD Directive 5000.1, scheduled for late this calendar year, is an expression of the urgently felt need to use every available forum to describe the letter and intent of the acquisition improvement actions.

Background

One of Mr. Carlucci's first actions upon arriving in the Department of Defense was to ask people in the acquisition community to identify their most serious concerns. He received answers from all sectors, from Congress to the program manager. He found concerns with program turbulence, and the extraordinary difficulty we have with holding to our long-range plans. He found concerns with the burden of reporting and reviewing, and with the seemingly endless rounds of briefings. He found concerns with the cost of acquisitions, particularly the overhead and indirect costs, and with our inability to estimate costs realistically. He found concerns with the aging and shrinking industrial base. He found concerns with the length of the acquisition process, occasioned by many causes (sometimes by technical difficulties, sometimes by the decision-making process, often by the constraints of the budget process). He found concerns with the cost of ownership, including the costs of maintenance and support. And finally, he found concerns that performance and readiness of systems in the field and in the fleet were far below the level anticipated and needed.

At the same time, Mr. Carlucci was keenly aware of the numerous studies of the acquisition process that had been conducted over the past decade (Figure 2). In his view, we did not need another study—the time for action had arrived. It would, of course, be wrong to suggest that during the last decade no progress had been made in refining the acquisition process. The publications of DOD Directive 5000.1 and of OMB Circular A-109 were major achievements in the definition and refinement of the acquisition process. Of particular note in both of these

FIGURE 2
Major Studies of the Acquisition Process



documents is the strong emphasis on tailoring the acquisition process to yield the optimum acquisition strategy. In spite of such improvements, however, Mr. Carlucci's view was that in the past too much emphasis had been put on studying problems and too little on implementing solutions. Thus, the five working groups were chartered not to conduct yet another study of the acquisition process, but to look at solutions that had been proposed in the past and determine a course for future actions. Out of these study groups' findings and recommendations came the 32 actions designed to: (1) promote decentralization and participative management, (2) improve the planning and execution of weapon system programs, (3) strengthen the industrial base that supports the Department of Defense, (4) increase the readiness of weapon systems, particularly in the early stages of their lives in the field, and (5) reduce the burdensome administrative requirements that make the acquisition process more costly and time-consuming than necessary.

The 32 Acquisition Improvement Actions

Now let's look more closely at the specific actions. We will not examine them all in detail or in numerical order, but will instead consider them as they relate to the five primary objectives listed in the previous paragraph.

The 32 acquisition improvement actions are firmly rooted in eight fundamental management principles (see Actions 1 and 32). These principles were stated by Mr. Vincent Puritano, Executive Assistant to the Deputy Secretary of Defense, in an article in the October 1981 issue of *Defense/81* as follows:

> We must improve long-range planning to enhance acquisition program stability.
>
> Both OSD and the Services must delegate more responsibility, authority and accountability for programs; in particular, the Service program manager should have the responsibility, authority and resources adequate to execute efficiently the program for which he is responsible.
>
> We must examine evoluationary alternatives which use a lower risk approach to technology than solutions at the frontier of technology.
>
> We must achieve more economic rates of production.
>
> We must realistically cost, budget, and fully fund in the Five Year Defense Plan, and Extended Planning Annex, procurement, logistics and manpower for major acquisition programs.
>
> Readiness and sustainability of deployed weapons are primary objectives and must be considered from the start of weapon system programs.
>
> A strong industrial base is necessary for a strong defense. The proper arms-length relationships with industry should not be interpreted by DOD or industry as adversarial.
>
> Defense managers at all levels should expand their efforts to obtain maximum competition for their contractual requirements.

Promote Decentralization and Participative Management

The first group of actions reflects what has been variously called "controlled decentralization" and "participative management," and is in line with Deputy Secretary Carlucci's desire for a major change in acquisition philosophy.

Our current way of doing business reflects two decades of increasing centralization. We have seen an increase in the number of reports and briefings; we have observed an increase in the number of directives and regulations; and we have experienced delays in the decision-making process.

To illustrate this point, consider the data in Figure 3, which illustrates the tortuous, time-consuming path to a Defense Systems Acquisition Review Council (DSARC) review. In fact, very few of these prebriefings are actually presented to offices within the Office of the Secretary of Defense; most are offered to line and staff organizations within the services.

FIGURE 3
DSARC Prebriefings

Program	Number
F-16 Aircraft	56
Joint Tactical Information Distribution System (JTIDS)	42
Patriot Air Defense System	40
F-18 Aircraft	72

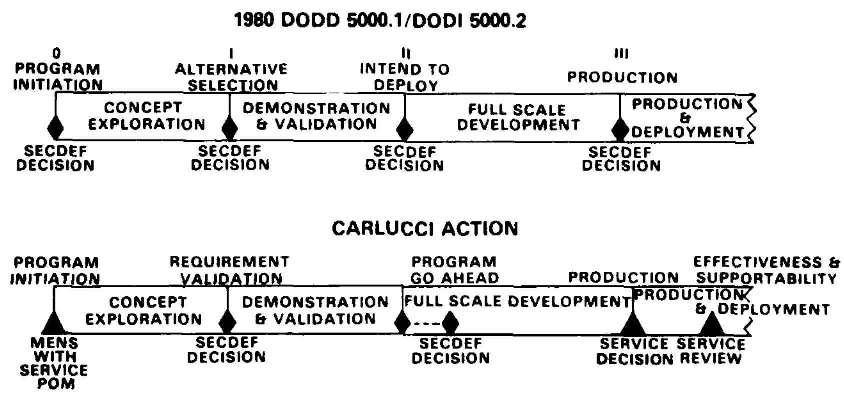
Lest there be a misunderstanding, it should be noted that centralization has its distinct advantages. Moreover, every new regulation, policy, and procedure is conceived with the objective of helping us avoid a pitfall. However, we have become so superbly conscious of avoiding errors that we have added a heavy overburden to our process. (Note that in geology, "overburden" refers to the material that must be removed before one gets to the mineral-bearing ore in a mine.)

The objective of this thrust is to reverse some elements of the trend towards centralization. A particularly definitive statement of the Deputy Secretary's intent is provided in his 27 March memorandum: "We will achieve better defense management by working toward a system of *centralized control of executive policy direction* and more *decentralized policy execution* (emphasis added)." Thus, there is a clear delineation of responsibility: There are some decisions which clearly should be reserved for the highest levels; however, in most cases, decisions can and should be made at substantially lower levels in the organization. The succinct guideline for this distinction is stated in one of the management principles within Action 1: "Responsibility, authority and accountability for programs should be at the lowest levels of the organization at which a total view of the program rests."

The following five actions directly support this thrust:

24. Reduce the number of Secretary of Defense decisions.
28. Raise the dollar threshold used to select major programs for DSARC review.
17. Decrease DSARC briefing and data requirements.
26. Revise DSARC membership to include the appropriate service secretary.
27. Retain the Under Secretary of Defense for Research and Engineering as the Defense Acquisition Executive (DAE).

FIGURE 4
Major Systems Acquisition Process



Action 24 cuts in half the number of Secretary of Defense decisions for major weapon system programs and reduces the number of DSARC reviews from three to two. The new process, illustrated by Figure 4, is already in force. Four features deserve special attention.

(1) Note that, although the Mission Element Need Statement (MENS) is no longer specifically approved by the Secretary of Defense (Milestone 0), the new procedure requires that the MENS be submitted with the service program objectives memorandum (POM). Thus, the Secretary of Defense *does* tacitly approve the MENS when he approves the POM.

(2) The new milestone, entitled Requirement Validation, is effectively the same as the old Milestone I, Alternative Selection.

(3) The new milestone entitled Program Go-Ahead is no longer rigidly tied to the beginning of the full-scale development phase of the program. The objective of this new arrangement is to allow the program manager more flexibility in the development of his acquisition strategy. On the one hand, he may wish to stick with the traditional definition of Milestone II. On the other hand, he may wish to delay the Program Go-Ahead Milestone until after preliminary design review (PDR) or even after complete design review (CDR) so that he can develop a better view of the performance, cost, schedule, industrial base preparedness, supportability, and testing prior to the Secretary of Defense decision to commit to completion of full-scale development, production, and deployment. Normally the ac-

quisition strategy, and hence the timing of the Program Go-Ahead milestone, will be defined and agreed upon at the Requirement Validation milestone. Regardless of the timing of the Program Go-Ahead Milestone, all contractual instruments must be responsive to the decisions of the Secretary of Defense and, for example, provide for the termination of the program at the Program Go-Ahead milestone (should the Secretary of Defense make this decision). (Needless to say, the intent of this action is not to create another milestone; the Program Go-Ahead Milestone *replaces* the Intend to Deploy milestone).

(4) The old Production Decision milestone has been returned to the services with the following proviso: The program must be within performance, cost, and schedule windows established at the Progam Go-Ahead milestone.

In a related action, the thresholds for programs to qualify for DSARC review have been doubled. The new thresholds are $200 million in research, development, test and evaluation funds and $1 billion in procurement funds. Note that the revised thresholds are stated in terms of FY 80 dollars; thus there is a built-in "cost of business" adjustment. This action has resulted in 10 programs being removed from the DSARC review process.

A brief note is in order regarding the major programs which were initiated "pre-Carlucci" and are *not* below the new DSARC review thresholds. These programs are being examined on a case-by-case basis to determine whether further OSD reviews are warranted. It is interesting to note in this regard that, in several cases (the KC-135 re-engining and the Tomahawk programs, for example), the Milestone III review has been delegated to the services.

Some progress is also being made in reducing the amount of material that will be prepared for a typical DSARC review. For example, the integrated program summary (IPS) has been eliminated for the Requirement Validation reviews; this action will, of course, require that the corresponding decision coordinating paper (DCP) contain complete cost information on the alternatives to be considered. Dr. Richard D. DeLauer, Under Secretary of Defense for Research and Engineering, is also examining the possibility of shortening the IPS for the Program Go-Ahead reviews scheduled to be held at OSD.

In a fourth action dealing with the DSARC process, the membership of the DSARC has been increased to give the services a greater voice in the DSARC process. As noted in Figure 5, the service secretary of the appropriate service has been added to the DSARC membership. In the case of joint-service programs such as the advanced medium range air-to-air missile (AMRAAM) program, the secretaries of all involved services will be members of the Council.

FIGURE 5
New DSARC Membership

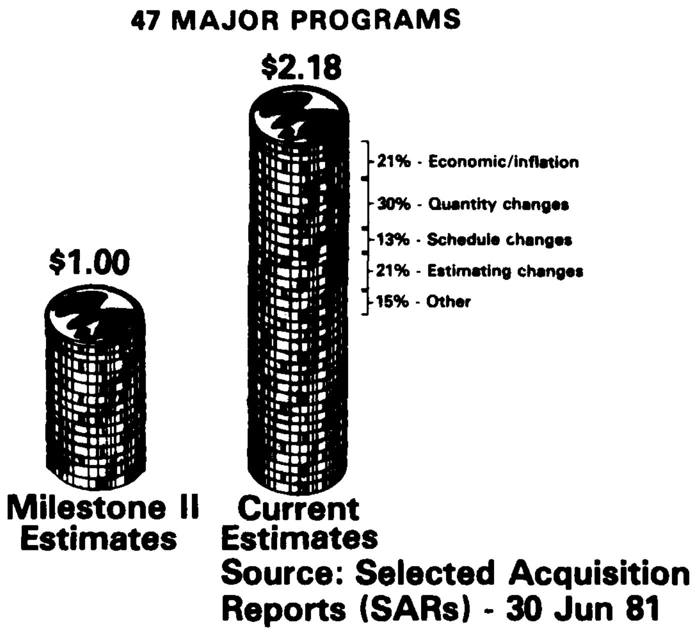
- **Defense Acquisition Executive (DAE, USDRE), Chairman**
- **USDP - Under Secretary of Defense for Policy**
- **ASD(MRA&L) - Assistant Secretary of Defense (Manpower, Reserve Affairs & Logistics)**
- **ASD(C) - Assistant Secretary of Defense (Comptroller)**
- **Director, Program Analysis and Evaluation**
- **Chairman, Joint Chiefs of Staff or his designee**
- **Service Secretary or his designee**

Improving Planning and Execution

The root cause of difficulties in the area of planning and execution is, of course, uncertainty. Technical uncertainties are the most commonly cited. Technical uncertainties can also lead to schedule uncertainties; however, there are other sources of schedule uncertainty. Foremost among these is the necessity to stretch out a program in order to accommodate all of the desired programs within the constraints of a fixed budget. Cost uncertainties arise both from technical uncertainties and also from schedule uncertainties. But cost uncertainties, like schedule uncertainties, have independent origins of their own. In some cases, we are simply not able to estimate with the desired accuracy the future cost of research and development or of production programs.

Common techniques for coping with uncertainties are well known. We adjust production rates annually; we cut soft programs in order to make funds available to other programs; we delete hardware items such as test hardware, and so forth. Among the consequences of these actions are program turbulence and cost growth. The extent of turbulence in the 47 major programs reported in the Selected Acquisition Reports (SARs) dated 30 June 1981 is illustrated by the following data: With respect to the acquisition strategy laid down at Milestone II, 40 of the programs have experienced changes in the number of units to be pro-

FIGURE 6
Cost Growth



cured, and 41 of the programs have experienced schedule changes. Cost growth among these 47 major programs is illustrated in Figure 6. Note that slightly more than one-fifth of the 118 percent cost growth can be attributed to quantity and schedule changes. Cost growth due to estimating changes contributes another one-fifth.

An additional consequence of our current techniques for dealing with uncertainties is our lack of credibility both in the view of the Congress and also in the eyes of many people in the industrial sector. This consequence is a direct result of our apparent inability to stabilize our programs and stem the tide of cost growth. The Deputy Secretary of Defense is particularly concerned with this lack of credibility because it not only encourages the Congress to take a direct role in the management of our programs but also discourages much-needed capital investment by the undustrial sector.

The uncertainties which are not within our grasp are primarily of a technical origin. They arise, in part, from the need to insert new technology as fast as possible to offset the numerical advantages of the Soviet Union and the Warsaw Pact. The following four actions are designed specifically to help cope with technical uncertainties:

2. Increase use of Pre-Planned Product Improvement (P^3I).
11. Budget for Technological Risk.
12. Provide Front-End Funding for Test Hardware.
15. Enhance Funding Flexibility.

Pre-planned product improvement (Action 2) reduces technical risk and increases the likelihood of meeting the initial operational capability (IOC) date by allowing the weapon system to be fielded *without* the ultimate state-of-the-art technology but *with* provisions for incorporating the higher technology at a later date when it has matured. There is, of course, an ancillary benefit in that a weapon system designed in anticipation of product improvements may provide a low-cost alternative to the development of an entirely new weapon system to counter a future threat.

To be effective, pre-planned product improvement must be an integral part of the acquisition strategy; this requires that the planning begin early in the acquisition cycle and that funds be set aside to develop the new technology. Note that, while P^3I is often thought of as a technique for upgrading the performance of a system, it may also be effectively used to upgrade the supportability and maintainability. Needless to say, the existence of a P^3I program should not be used as an excuse for allowing fielding of a system which fails to meet its initial performance and readiness goals.

Action 11 recognizes the traditional difficulty we have had in justifying and protecting funds (a type of management reserve) for unanticipated technical difficulties. In recent years both the Army and the Air Force have developed scientifically sound techniques for estimating the risk of a program and the contingency funds that should be set aside to cope with unanticipated difficulties. These techniques consider each element of the program (e.g., the elements in the work breakdown structure), assign a risk to each element, and use mathematical methods to combine the data and develop a measure of the risk for the whole program.

In this context, Action 11 requires the services to increase their efforts to quantify risk and to expand the use of budgeted funds to deal with uncertainty. Needless to say, there is an implied pledge by the DOD that effectively justified reserves will not be the first targets for budget cutting and redistribution exercises.

The primary objective of Action 12 is to reduce the length of the acquisition cycle while holding the risk at an acceptable level by providing additional test hardware so that developmental and operational tests can be conducted concurrently. Needless to say, this requires that the test hardware be built early in the program, and that the program manager resist the temptation (when faced with other pressing needs) to discount the importance of testing. Action 12 also stresses the importance of combined environmental tests, and the importance of the test-fix-test process (starting early in the program).

Action 15 recognizes that in some cases it is desirable to convert production moneys into RDT&E funds; a case in point is a program which is slated to enter production but has been delayed due to technical difficulties. Although the DOD has statutory authority to reprogram a total of $750 million a year between authorizations, the institutional impediments (review by OMB and by congressional oversight committees) virtually prevent these reprogramming actions. DOD is currently seeking relief from these impediments.

In addition to technical difficulties, a key source of program turbulence is the lack of discipline with which we plan for the out years. The following four actions deal directly with planning:

25. Submit the MENS with the Service POM.
29. Integrate the DSARC and PPBS Processes.
4. Increase Program Stability.
7. Use Economical Production Rates.

Mr. Carlucci put his finger on a key element of the problem in the following quotation from his 27 March 1981 memorandum on management of the PPBS:

> I agree with the consensus that we must both improve strategic planning in the early planning phase of the PPBS cycle and strengthen long-range planning throughout the other phases of the PPBS. This calls for a more disciplined planning process that will provide the framework, the goals and objectives, the appropriate military strategies, and the risks associated with the optimum allocation of available resources.

In this context, a key feature of the 27 March 1981 memorandum is the redefinition of the membership and role of the Defense Resources Board (DRB). The DRB is chaired by the Deputy Secretary of Defense and has been expanded to include 17 regular members, including all the members of the DSARC. Its charter includes:

—Reviewing proposed planning guidance;

—Managing the program and budget review process;

—Advising the Secretary of Defense on policy, planning, program and budget issues and proposed decisions;

—Evaluating and reviewing high priority programs on a regular basis;
—Assuring that major acquisition systems are more closely aligned to the PPBS.

In addition, the 27 March 1981 memorandum makes other specific changes to the PPBS process. For example, it required that the documentation for the FY 83 POM be cut by 50 percent and required that the comptroller slash the huge amount of paperwork required for the zero base budgeting (ZBB) process. More importantly, the memorandum charged key OSD offices with developing plans for significantly improving the OSD programming process. Thus, in a sense, the four acquisition improvement actions are but a small part of a much larger activity within the DOD.

Actions 25 and 29 are aimed at bridging the gap between the DSARC process and the PPBS process. Specifically, these actions require that, at each of the first three decisions points in a program (Program Initiation, Requirement Validation, and Program Go-Ahead), the service guarantee that adequate funds are budgeted to carry the program to the next milestone. The requirement to submit the MENS with the POM was described earlier. In the case of the Requirement Validation and Program Go-Ahead milestones, the service secretary will assure the DSARC that sufficient resources are provided in the Five Year Defense Plan and the Extended Planning Annex (or can be programmed) to execute the program as recommended.

Action 4 requires that the Secretary of Defense, OSD, and the services fully fund both the R&D and the procurement of major systems at levels necessary to protect the acquisition strategy established when the program was baselined. Programs will be reviewed for compliance with this requirement during program and budget review by the Defense Resources Board.

So far in this section, attention has been focused on those actions which deal with technological risk and with planning. The following six actions are primarily aimed at improving costing and execution of weapon system programs.

6. Budget to Most Likely Cost.
8. Assure Appropriate Contract Type.
20. Improve the Source Selection Process.
22. Provide More Appropriate Design-to-Cost Goals.
18. Budget Weapons Systems for Inflation.
19. Forecast Business Base Conditions at Major Defense Plants.

It is, of course, realized that our cost estimating and budgeting processes have significant room for improvement. At the same time, it is recognized that the problem is compounded as we struggle to fit more and more programs within the confines of a fixed budget. In response to this constraint, we often feel compelled to accept intentionally low initial cost estimates; this process, usually referred to as "buying in," frequently leads to apparent cost overruns and criticism of our management abilities.

The thrust here is twofold. On the one hand, we in the federal government are being required to take a much more vigorous role in cost estimating. We are asked to pay particular attention to predictable cost increases due to risk. And we are asked to develop more reliable estimates of cost and to stop relying so heavily on contractor estimates. On the other hand, the contractor is also required to give us more accurate cost estimates. To this end, a series of specific actions has been identified: (1) Improve the source selection process to place added emphasis on past performance, schedule realism, facilitization plans, and cost credibility; (2) Provide contractual incentives to encourage good performance with respect to cost goals; (3) Make design-to-cost a more viable tool by delaying fee awards until after the initial items have come off the production line and real production costs can be determined.

The objective of these actions is to reduce the number of overruns and to reduce the number of times that contractors feel they must "buy-in" in order to compete. At the same time, DOD recognizes that there are some other actions it can take to make your job easier. One of these is helping the program manager cope with unrealistic inflation rates. The difficulty with this initiative is, of course, the political implications. Effective techniques are being studied.

The last action in this group reflects the fact that fluctuations in DOD and non-DOD work tend to distort business base projections and sometimes seriously increase overhead costs. To offset this situation, the OSD Cost Analysis Improvement Group (CAIG) will collect data and assist in improving forecasting.

Improve Industrial Productivity

The third major thrust of the acquisition improvement actions is to improve industrial productivity. Note at the outset, however, that this is a small piece of a much larger activity in the Department of Defense. The Department of Defense has prepared a plan, entitled "Action Plan for Improvement of Industrial Responsiveness," which is designed to significantly strengthen the industrial base. A tri-service committee has been established to implement numerous action items within this plan. The stated objectives of this plan are to:

—Enable American industry to undertake a program of capital investment;

—Improve American self-sufficiency in the area of critical raw materials;

—Ensure sufficient skilled manpower exists to meet the demand of American industry;

—Improve the quality of American workmanship and products;

—Impose stability on military procurement programs and resource demands;

—Make the defense market an attractive place for American industry to do business;

—Make military equipment designs compatible with commercial industrial production capabilities;
—Create an industrial base that is responsive to mobilization needs.

The increase in lead times illustrated in Figure 7 is just one indicator of the problems which the industrial base is facing. Note that the data in this chart reflect the mid-1980 time frame and that in recent months lead times have improved markedly. Nevertheless the data are significant reminders of the inability of the industry to cope with fluctuations in demand.

FIGURE 7
Increases in Lead Times

System	1977 (Months)	1980 (Months)	Drivers
F-15	36	41	Landing gear
F-16	28	42	Servo actuators
A-10	29	49	Landing gear
F100 Engine	19	37	Forgings
TF34 Engine	20	39	Forgings

Source: Report of the Defense Science Board 1980 Summer Study Panel on Industrial Responsiveness, January 1981

The fundamental thrust of the actions in this area is to create a favorable environment for capital investment by the industries. It is firmly believed that, with appropriate incentives, the industry will go a long way toward curing its own ills. The following actions address this area:

5. Encourage Capital Investment to Enhance Productivity.
3. Implement Multiyear Procurement.
32. Increase Competition.

Action 5 contains more than a half dozen specific actions which are designed to stimulate capital investment and ease cash flow problems. Some of these actions already have been accomplished; for example, progress payments have been accelerated, and the new tax law contains more liberal capital equipment

depreciation provisions. Other actions, such as the initiative to repeal the Vinson-Trammell Act, are still in progress.

Action 5 also encourages the services to place increased emphasis on their manufacturing technology programs. These programs are, of course, already strongly supported by the services. It is worth noting in passing that it is entirely appropriate to pursue a manufacturing technology program in parallel with an RDT&E program.

Multiyear procurement, used when appropriate, has two advantages. On the one hand, it creates a secure climate in which contractors will more readily make capital equipment investments. On the other hand, it permits the contractor to buy materials and components in more economic lot sizes; a single buy can, for example, provide the requirements for an entire 5-year contract. It has been estimated that 10 to 15 percent can be saved through purchases of this sort.

The principal unresolved issue with respect to multiyear procurement is budgeting for the cancellation ceiling. The requirement to budget for cancellation ceilings would tie up substantial fractions on the total obligation authority (TOA) and would thus make multiyear procurement a less attractive option in most instances.

Mr. Carlucci added Action 32, Competition, to the original 31 actions on 27 July. The primary objectives of competition are to stimulate innovation (both in design and in manufacturing practice) and to stimulate investment. Provided the competition is effective (and not a *pro forma* square-filling exercise), the program manager potentially can realize both cost savings and risk reduction. At the same time, the industrial base is strengthened through investment in technology and in productivity. Needless to say, indiscriminate enforcement of competition leads to senseless expenditure of government *and* industrial funds. Thus the program manager must evaluate his opportunities for competition in terms of cost, potential for cost reduction, and risk reduction.

Increase Readiness

The fourth thrust of the actions to improve defense acquisition is to improve the readiness of systems in the field. Concerns in this area include the delayed entry of systems into the field, the delayed support of systems in the field, and the high cost of ownership once the systems have been fielded. The costs of ownership include the full spectrum of operational, maintenance, and support costs.

The central theme running through all five of the actions dealing with readiness was explictly stated in Action 1, Management Principles:

> Improved readiness is a primary objective of the acquisition process, of comparable importance to reduced unit cost or reduced ac-

quisition time. Resources to achieve readiness will receive the same emphasis as those required to achieve schedule or performance objectives.

The five actions listed below single-mindedly echo this theme:

9. Improve System Support and Readiness.
31. Improve Reliability and Support for Shortened Acquisition Cycles.
21. Develop and Use Standard Operational and Support Systems.
16. Provide Contractor Incentives to Improve Reliability and Support.
30. Increase Program Manager Visibility of Support Resources.

It has, of course, been recognized for many years that a weapon system can be designed to incorporate features which facilitate its supportability and increase its readiness. A case in point is the F-18 aircraft. Moreover, since the vast majority of weapon system costs are determined by decisions that are made very early in the program, it is vitally important to consider logistics at the earliest possible moment in the program.

For those reasons, Secretary Weinberger and Deputy Secretary Carlucci felt that it was necessary to challenge the program manager in the stiffest possible terms. The reader is encouraged to study Actions 9 and 31 particularly.

(1) The program manager must define the readiness objectives for the system as early as possible and must be prepared to defend these objectives at the Requirement Validation milestone review. The readiness objectives of concern at this point go far beyond the normal items such as mean time between failure (MTBF), and address real system capabilities such as the ability to generate sorties.

(2) The program manager must design reliability and supportability into his weapon system and explicitly earmark resources early in the weapon system program to support these design efforts. The ultimate objective is to conserve the funds needed to support the system after it has been fielded.

(3) Particularly in the case of "fast-track" programs, the program manager must examine the feasibility and potential payoff of concurrent development and testing phases.

(4) The program manager must begin the iterative testing-design phases early in the program so that the system can mature in an orderly manner.

(5) The services are encouraged to target selected fc ce elements for major upgrades, which will make them significantly less dependent upon logistic tails. This, of course, entails even more RDT&E effort.

Action 21 echoes the well-known requirement that standard operational and support systems be used. However, the emphasis of this action is on RDT&E of new standard systems and the associated technology. Items of particular interest

in this group include both avionics equipment and test systems.

Action 16 specifically recognizes the validity of the use of contractual incentives as a technique for stimulating the contractor to pay more attention to reliability, maintainability, supportability, etc. The program manager should include logistics considerations among the source selection criteria, write specific incentives into the contract itself, and consider the use (where appropriate) of instruments such as reliability improvement warranties (RIWs). In the F-16 program, for example, nine separate items are covered by RIWs, and two items have mean-time-between-failure guarantees.

One last item deserves special mention: Action 30 recognizes that, because of the nature of the PPBS process, the program manager can sometimes be unaware of logistics decisions that directly impact the support of the system he is developing. In an attempt to ease this difficulty, both the OSD and the services are developing and implementing procedures which will give the program manager more visibility into resource decisions relating to his support assets.

Reduce Administrative Overhead Cost and Time

The fifth and final thrust of the actions to improve defense acquisition is to attack those legal requirements and administrative arrangements which add time and cost to the acquisition of weapon systems. The concerns include overmanagement at all levels of the government, the overall impact of government constraints, both administrative and legislative, and the impact of various outdated laws, directives, instructions, and regulations.

The following three actions provide an umbrella for a series of specific initiatives:

13. Reduce Governmental Legislation Related to Acquisition.
14. Reduce the Number of DOD Directives.
10. Reduce the Administrative Cost and Time to Procure Items.

Action 13 is designed to reduce the impact of excessively burdensome legislative programs. At the outset, it must be admitted that each legislative action that affects the acquisition process has its own appropriate goal. However, it has been possible to identify some legislative requirements whose goals are no longer particularly appropriate, and to identify some other legislative requirements whose impact on the defense acquisition process is much more severe than the benefits accrued as the result of the legislative action. It has therefore been possible to identify several target legislative measures. For example, in the view of many people, the statutory limitation on fees for cost-plus-fixed-fee contracts is outmoded and should be eliminated.

In some cases, we simply "do it to ourselves." A classic example is the growth of DOD directives and instructions. It has been 10 years since the last purge of directives and instructions, which reduced the number of such documents from 140 to 69. Now, with the number of directives and instructions again approaching 140, the process has begun once again by the direction of Mr. Carlucci. In addition, in an effort to hold down the number of directives and instructions in the future, the Defense Acquisition Executive has been designated as the sole issuer of future DOD directives related to acquisition.

Action 10 deals with raising the thresholds for various administrative actions. Most of these thresholds were established many years ago and have not kept pace with inflation. As a specific case in point, Action 10 seeks to raise the reprogramming thresholds from $2 million to $10 million for RDT&E appropriations and from $5 million to $25 million for procurement appropriations. An interesting innovation in the current action is the suggestion to tie the new thresholds to inflation. Action 10 also seeks to relieve the amount of paperwork and administrative overhead. For example, it encourages the use of Class determinations and findings (D&Fs), an action that is explicitly permitted by current directives but often frowned upon in practice.

Conclusion

This brings us to the conclusion; as we reflect back across the specific actions, we must keep in mind that they cannot be applied blindly to all programs. Indeed, by their very nature, these actions require that the program manager make trade-offs—make decisions among the many opportunities and challenges offered by these actions.

Figure 8 gives, in summary form, a status report on the implementation of the 32 actions to improve defense acquisition. With respect to the data displayed here, two observations are important. First, 11 of the actions (or parts of them) have been accomplished; thus, significant steps have already been taken toward improving the acquisition process. Second, 17 of the actions are now in your court; in most cases, you—the program manager—are in the best position to determine whether each of these 17 actions is appropriate for your program. You—the program manager—have the opportunity to contribute significantly to the overall improvement of the acquisition process.

There are many implications both for the services and for the program managers. Perhaps most important as far as the services are concerned is the expectation that these actions will be endorsed by the services and that they will be passed down the chain of command to the program managers. There is the firm expectation that responsibility, authority, and accountability will be delegated to a much greater degree than is done today. There is the further expectation that

FIGURE 8
Score Card

NOTE:
Since some actions have several parts, they may be counted in two or even all three columns.

	ACCOMPLISHED	IN PM'S COURT	IN PROGRESS
CONTROLLED DECENTRALIZATION AND PARTICIPATIVE MANAGEMENT	5	1	1
PLANNING AND EXECUTION	2	9	3
INDUSTRIAL BASE	1	3	2
READINESS	-	4	1
ADMINISTRATIVE OVERHEAD COSTS AND TIME	1	-	3
ACTIONS 1 AND 23	2	-	-

the services will reduce the number of reporting and reviewing requirements, thus freeing the program managers to do other tasks implied by the acquisition improvement actions. Indeed, although the DOD can take the lead and can make the program manager's life a little bit easier, the Department of Defense must rely on the services to make the big impact on the environment within which the program manager operates.

In addition, Mr. Carlucci has placed a great deal of emphasis upon program stability, charged the services to develop realistic plans, and insisted that these plans be considered as contracts between the services and the Department of Defense.

The program manager, for his part, has a lot of things to think about. At the start, he is encouraged to tailor his acquisition strategy, and to put money "up-front" with the expectation that money spent up-front will reduce the total cost of the acquisition. The program manager is asked to spend more time with realistic costing, and to encourage the contractors to do the same. The program manager should investigate the use of multiyear procurements to lend stability to his pro-

gram. The program manager should investigate the use of a wide variety of incentives both to encourage the strengthening of the industrial base and to encourage quality performance on the part of contractors. The program manager is encouraged to budget for risk, and told tacitly that these funds will not be held in jeopardy. The program manager is asked to examine the evolutionary introduction of new technology. And finally, the program manager is asked to put much more emphasis on integrated logistics support throughout the acquisition process. To help the program manager in these many tasks, he is promised increased financial flexibility in dealing with the uncertainties he is certain to encounter. He is promised that the load of reporting and reviewing and briefing will be reduced. And he is promised that the burdensome load of legislative and regulatory requirements will be reduced.

In some respects the Department of Defense Acquisition Improvement Program has created a new program management environment. One of the most obvious characteristics of this new environment is the insistence in many of the actions that additional funds be spent "up-front," with the expectation that the benefits will be reaped later in the life cycle of the weapon system. Many examples come to mind: front-end funding for test hardware, pre-planned product improvement, economic production rates, just to name a few. Even with the currently projected FY 82 DOD budget, there is no way that all the implied fiscal requirements can be met. The implication is clear: High-priority programs will receive strong support, and low-priority programs will be cut. The measure of our management ability will be our ability to make the tough decisions this implies.

As we try to characterize this new environment further, several key words come to mind.

The program manager will have greater *authority* and *responsibility* in the new environment, and will have more *flexibility* to deal with the uncertainties he is certain to encounter. At the same time, a great deal is expected of the program manager and he will be held *accountable* for his actions. Indeed, his credibility and the credibility of his program will be gauged by how well he makes his decisions.

Credibility is crucially important in the larger context as well. It is vitally important that we in the DOD reestablish our credibility in the view of Congress and in the view of our industrial counterparts. To do this, we must demonstrate both the *commitment* and the *discipline* to manage our programs well. We must erase the image that DOD programs are out of control.

There is a tremendous amount of *excitement* about the 32 actions. This excitement is engendered in part by the fact that the services have been involved in the development of the actions from the first day. Thus, even the generation of the

actions illustrates the participative management that Mr. Carlucci is seeking. The excitement also stems from the realization that, for the first time in many years, some real changes in the acquisition process may be possible. And, the excitement stems from the realization that the Department of Defense, beginning with Secretary Weinberger, Deputy Secretary Carlucci, and others, is absolutely committed to the implementation of these actions. And finally, there is the *urgency* I referred to in the introduction to this paper. As noted earlier, it will be necessary to have a large infusion of money right now in order to accomplish many of these actions. The FY 82 budget provides such a large infusion of money. Inasmuch as this could possibly be a singular event in time, it is imperative that these actions be pursued with utmost vigor and *urgency* at this time. The net result will be significant enhancement of our preparedness. ||

Human Factors in Weapon Design: The Performance Gap

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Dr. Jonathan Kaplan
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Years of extensive testing of military systems have shown that there is frequently a significant difference between the *potential*, or *designed*, performance of a system and its *actual* performance. This "performance gap," as it is called by the Army[1], can be attributed largely to the performance of the human component in the system. This paper examines one of the technologies capable of improving the performance of the human component, thereby narrowing the performance gap. It cites examples showing the effects of failure to apply this technology, and proposes changes to system development procedures which, if adopted, should lead to actual field performance of a system that closely approximates its predicted performance.

The human element in weapon system design is usually addressed in the discipline known as "human factors."[2] This field deals with ways to design hardware, software, environments, and procedures so that they fit human capabilities and thus produce the highest attainable system performance within the "design-to-cost" envelope. It contains elements from a number of other disciplines, including psychology, biology, bio-mechanics, medicine, mechanical and electrical engineering, physics, mathematics, and statistics. Issues of concern range from the apparently simple question of the physical fit of system operators with the system hardware to the more complex question of the amount and quality of work which can be performed by the real user population under genuine battlefield conditions. Human factors specialists study system concepts to identify and remove sources of human error which could reduce system effectiveness.

1. *Analyzing Training Effectiveness*, TRADOC Pamphlet 71-8, U.S. Army Training and Doctrine Command, Fort Monroe, Va., February 1976, p. II-2.
2. The discipline referred to here as "human factors" is sometimes known as human factors engineering, human engineering, human factors psychology, or ergonomics.

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Examples

Unfortunately, the human factors discipline has often not had sufficient impact on system design to prevent problems in the man/machine interface. It is interesting to reflect on some examples of the effects of this lack of impact. For reasons of clarity, relatively simple, but real and significant, examples are presented here.

ANTHROPOMETRICS

Some of the work of human factors is based on anthropometric data, which consist of measurements of physical features of the human body. In theory, weapon systems are designed so that their dimensions permit an acceptably large subset of the potential user population to fit in them and perform all of the tasks required to operate and maintain them. One of the dimensions that is frequently considered is, of course, height. Usually, system hardware is designed so that it can be operated by people between the fifth and ninety-fifth percentiles in height. Unfortunately, this simplistic fifth-to-ninety-fifth-percentile rule sometimes obscures the way real people are constructed. That is, there are many individuals with long legs and short torsos, short legs and long torsos, long thighs and short calves, etc. One of the results of replacing accurate representation with simplicity is the existence of weapon systems that do not fit their users.

In one such instance, a high-performance jet fighter does not have sufficient clearance for the lower legs of a significant percentage of the pilot population. This design was apparently made without considering the variability of actual human configuration. There has been speculation, based on measurements and careful readings of anthropometric tables, that upon ejection, a significant number of pilots of this aircraft would break both their legs—with consequences both painful and expensive.

Another example that has some anthropometric elements involves the "design-eye" position in aircraft. It is desirable for aircraft pilots to be able to see their landing area over the aircraft's nose. To facilitate this, the pilot is so situated in the cockpit that when the aircraft is in the appropriate nose-high landing position, the landing area can be seen. When he can see his landing area and he is sitting in the expected envelope of the cockpit, he is in the design-eye position for which the cockpit was configured. Unfortunately, aircraft oscillate about the ideal position from which the landing area can be seen. The pilot's view remains unobstructed for only a portion of this oscillation. (This implies that the design-eye position ought to be larger and therefore more forgiving of airplane movement.) Pilots attempt to correct this deficiency by raising their seats. If they raise the seats high enough, they put themselves in another area from which they can

see the landing area more easily even if the aircraft oscillates. It also, however, puts them in a position for which their controls and displays were not designed, as well as positioning their helmets near, or in contact with, the canopy. Such repositioning has various negative side effects. It makes it more difficult to read displays and to manipulate controls. If the airplane makes any sudden vertical movements, the probability of pilot injury or loss of aircraft control becomes undesirably high. This example illustrates the ripple effect of designing hardware without adequate consideration of its effects on operator performance.

DESIGN OF OPERATING CONTROLS

Disregard of human factors principles and research findings has led to a number of peculiarities in the design and placement of controls. Two illustrations of these peculiarities follow. There was once a military aircraft with variable-sweep wings. As the aircraft increased its speed, its wings were supposed to be swept further back. A decision had to be made about the control that initiated the wing movement. Common sense seemed to dictate that this control follow the pattern of the throttle. That is, when a pilot wants to go faster he pushes his throttle forward; therefore, he should also push his wing control forward. Looked at another way, if the pilot wanted the wings to move backward, he would push the control forward. This particular version of common sense turned out to be a mistake which frequently saw pilots engaging in control reversals. As it turned out, when pilots think about moving their wings backward, they associate this with moving the control backward. When they think about moving their wings forward, they associate it with moving the control forward. In this case, the common sense of reasonable people was insufficient to preclude a human-factors problem.

The second illustration of peculiarities in control design involves a small autopilot on-and-off switch. Conventionally, aircraft automatic pilots are engaged and disengaged with the switch directions being relatively constant across different types of aircraft. This enables pilots to transfer their training from one aircraft to another. As a general rule, pilots prefer that differences in cockpits be held to a minimum. When cockpits are similar and pilots are put under high stress, they can revert to old habit patterns. For unclear reasons, the automatic pilot switch in question was designed so that its engagement-disengagement directions were reversed in a new aircraft. In a most unpleasant manner, it was discovered that if you put a pilot under stress with the new automatic pilot *on*, and he wished quickly to disengage it, he tended to revert to his previous habit pattern; that is, he would continue pushing the autopilot switch toward the *on* position. While this is an extremely simple human factors problem, it is representative of a large number of similar problems. It is small, simple, easily ignored, and dangerous. To locate a control properly in advance often

requires a careful, detailed human factors analysis of the components and configuration of the cockpit design. Such an analysis is all too infrequent.

DESIGN OF DISPLAYS

Displays constitute another major area which can provide illustrations of the effect of design in the absence of human factors inputs. Over a number of years, attempts have been made to develop and utilize a visual target acquisition system, or VTAS, in aircraft. Such a system projects a gun sight in front of the gunner's eye. He can then turn his head, locate a target, hold the sight on the target, and inform a computer that he wishes to attack that target. The computer locates the target by sensing the direction in which the gunner is looking. Early versions of such a system projected a gun sight onto a half-silvered mirror which was suspended by a wire in front of the gunner's eye. No one discovered in advance that people are made uncomfortable by having small objects dangling in front of their eyes. Also, the wire bent under G forces, interfering with its use. A later version projected the gun sight directly onto the gunner's helmet visor, producing a ring of light and various simple symbols.

Immediately prior to operational introduction, a human factors specialist tried out the system in a laboratory and discovered that it worked as advertised and was very impressive. He then took it outside and looked at the sky. He discovered that if one looked anywhere near the sun or any other bright object, the gun sight disappeared. At least this problem was corrected before the gun sight was fielded.

Another example in this area is that of head-up displays in aircraft. Such displays allow the pilot to see radar- or computer-generated displays and target information without having to look down at instruments inside the cockpit. Translating this display information into action usually requires the manipulation of controls, the use of other displays, and a return to the original display. This procedure is demanding, but possible, if the amount of information—particularly the number of targets—is small. As the amount of information increases, the pilot begins a cycle which normally ends in bewilderment and the commission of major errors: First he detects a target on his display. To take the required action, he must look away from that display, at his instruments and other displays. The action he takes changes the location of the targets and other information on the original display. However, when he looks back up at it to determine the effects of his actions and the current status of the situation, everything has changed. He has difficulty deciding which target is which, unless he looks at the display continuously, but he cannot perform his other functions properly if he does *not* look away. This is a human factors problem which is sophisticated, and which has not yet been adequately solved in a number of cases.

MATCHING TECHNOLOGY TO THE USER POPULATION

One of the most potentially difficult design problems appears when technological advances provide weapon systems that have significantly greater capabilities, but which also require an ascending level of performance from a user population with descending aptitude levels. There is a tendency today to design modern, sophisticated weapons without considering the ability of their real users to perform the more sophisticated tasks these weapons may require. There are current examples of armor systems with greater potentials which allegedly cannot be adequately operated by their users, so that the systems cannot engage in the advanced individual maneuvers of which they are theoretically capable.[3] Such anomalies occur when human factors inputs are not made at the system design stage. That is, to say it is reasonable, assuming one knows who will make up the user population, and further assuming one knows the characteristics and aptitudes of that population, that the abilities of that population should affect the design of the weapon system they are to use. Otherwise, the design process results in a system of great potential which can only be realized when operated by a population not available in the real world. It is the effectiveness of a weapon system when operated and maintained by its real users that determines its military utility, not simply an engineer's prediction based on an assumption of error-free human performance. Therefore, if the characteristics of user population are assumed to be either relatively constant or declining, significant efforts ought to be made in a human factors program (primarily in validating the allocation of functions between mankind and machine) to ensure that human performance requirements for operation and maintenance are consistent with the abilities of the intended users. Where such efforts are made, system effectiveness may increase (and life-cycle-system cost decrease) significantly more than by isolated advancements in hardware or technology.

Speculation on Neglect of Human Factors

It is our view, there are both attitudinal and procedural reasons why the human factors discipline has not always produced an adequate impact on system design. These reasons will be discussed in the paragraphs that follow.

ATTITUDINAL REASONS

Notwithstanding recent advances in computer-aided design, it is still a human being who makes design decisions in the development of new systems. Humans

3. *Strategy and Tactics No. 11*, New York: Simulations, Inc., November/December 1978, p. 23.

have attitudes, and attitudes affect their decision-making.[4] Moreover, the final decision-makers are themselves almost never human factors specialists. Finally, the matters of cost and schedule—not system effectiveness—often dominate the setting in which design decisions are made. ("After all," goes the familiar refrain, "if the user will increase training or get smarter operators, system performance should approach its potential.")

If the decison-maker knows something about human factors, has had some positive experiences with human factors specialists and their products, understands the real sources of human performance errors that affect the operational utility of systems, and does not object to design suggestions originating from "non-engineering" sources, human factors may be allowed sufficient resources to have an impact on design. If, however, the decision-maker knows little about either human factors or real sources of system error, has had unfortunate experiences with human factors and its practitioners, or feels that non-hardware-engineering sources add little that is useful to the design process, human factors is likely to be allowed to make only *pro forma* contributions; and interesting results, such as those previously described, may occur.

Even where a decision-maker is aware of the theoretical contributions of human factors to system effectiveness, in most projects there are fewer resources available than there are requests for them by engineering specialty programs. Human factors may then be forced into direct competiton with such programs as value engineering, reliability, maintainability, and safety. In resolving such competition, a prudent decision-maker may award resources to programs better able to quantify their return on investment than is human factors: As noted in one report:

> The inability to measure [its] value in terms of specific contributions to military systems performance has made the defense of system development resources for human factors increasingly difficult.[5]

There is a further source of bias in attitudes of engineering decision-makers toward human factors: Human factors data are collected through a combination of relatively objective measurement techniques and *opinion* surveying. Using opinions as a basis for either design or evaluation disturbs a number of people. It smacks of the so-called "soft" sciences and is not, somehow, truly scientific. Also, human factors often produces guidelines and solutions which are thought of as

4. B. Berelson and G. Steiner, *Human Behavior*, New York: Harcourt, Brace and World, Inc., 1964, p. 575.

5. H. E. Price, *et al.*, "Identification of System Metrics for Measuring the Contribution of Human Factors," Interim Report No. 2, Falls Church, Va.: BioTechnology, Inc., March 1980, p. 1-1.

the product of common sense, and therefore producible by anyone involved in the project—not merely by those trained in the arcane arts of whatever-it-is that human factors is. It may well be that some of human factors' findings may be thought of as common sense (apparently defined as something which is so simple and obvious as to be, in effect, self-evident); even though they derive from systematic, but less obvious, research. The most mysterious attribute of such so-called common sense is that it achieves its status only after someone has thought of it and, at least in military systems, it is frequently not thought of.

PROCEDURAL REASONS

Military system development in the United States is a joint venture of government and private industry. The military service normally provides the system specifications and the funding, and the business firm successful in the bidding process furnishes the detailed design of hardware, software, training, and logistic support. Both government and industry participate in the test and evaluation program. Because there are these two distinct roles, speculation on neglect of human factors is presented separately for each.

A defense contractor's neglect of human factors is the easier to set forth. The contractor makes a written commitment (enforceable in a court of law) to furnish supplies and services in the design and development of a new system. Normally in a research and development (R&D) contract, the specific services to be provided by the contractor are set forth in some detail; and the contractor is promised a sum of money upon their being rendered. The quickest, most legally sufficient, and most frequently heard explanation for a defense contractor's failure to include human factors efforts in a development program is that neither the RFP nor the contract required such a program. One must assume that the government agency which let the contract knows what it is doing; and if the contract and RFP requirements are not so written as to require a human factors program, then the contractor may legitimately assume the agency is not interested in its inclusion. Such a situation could be overcome by adequate preparation of the government's procurement package (see below).

Where an R&D contract does contain provisions for an adequate human factors program, it is theoretically possible that the system which ultimately emerges from the development process will be fully capable of meeting its designed effectiveness. If a performance gap is nevertheless found to exist, it is likely to have arisen from the nature of the contractor's design process. In almost all of American industry the human factors specialist is supposed to "help" or "assist" the principal designer—whether the latter is or is not eager for such assistance.[6] It

6. The Department of Defense fosters the notion that the contractor's system design effort will be performed by a happy, cooperative, interdisciplinary team, each member of which has separate and well-defined, but completely integrated, activities. See paragraph 10.2(3) of Data Item Description DI-H-7051, "Human Engineering Program Plan," U.S. Navy Publications Center, Philadelphia, Pa.

was suggested to the 1980 Congress of the Society of Automotive Engineers (SAE) that the efficacy of a company's human factors program might be improved if the cooperative method of including human factors in design were replaced by a competitive method.[7]

MILITARY PROCEDURES

Two principal factors handicap the military in seeking to include human factors in weapon system design: complexity and shared responsibility. The first is a characteristic of the scheme under which military materiel is developed and acquired. This scheme is depicted by a functional flowchart indicating which activities performed by whom are normally necessary in transitioning a new system from the drawing board into the hands of troops.[8] None of the models as originally published by the services included the steps necessary for systematic consideration or inclusion of human capabilities and limitations in weapon system design. However, the Army in 1969[9] and the Navy in 1977[10] each supplemented the already complicated acquisition models with even more complicated models setting forth those steps. There is no evidence to indicate that either model has had any significant impact on the weapon system acquisition process. It is not that these conceptual schemes have failed—they simply have not been tried.

The second handicapping factor (and the principal reason that the models lie unused) is that responsibility for the soldier (or sailor or airman) is so important that it's everyone's. In no other sphere of activity are the consequences of this (usually benign) shared responsibility more severe than in materiel development. For here, any innovation requires the willing participation (not mere acquiescence) of *all* of the commands and agencies who participate in the development program. It is not enough to have a materiel developer eager to satisfy "human factors engineering" requirements for a project if the combat developer has failed to postulate any; or to have a contractor willing to spend money to ensure that the system design accounts for the skill levels in the available manpower pool, if the materiel developer allocates no such money. Pulling together all of the participants in a materiel development project to ensure adequate attention to human factors considerations is an accomplishment which has thus far eluded military leaders. The Army recently released another, easier-to-read plan for

7. Under a competitive method, the human factors specialist would have access to all drawings, plans and other documents describing the evolving system—but not to the designers themselves. For each improvement proposed by the human factors specialist and accepted by management, the human factors specialist would be paid a bonus.

8. *Life Cycle System Management Model for Army Systems*, Department of the Army Pamphlet 11-25, May 1975.

9. *Manpower Resources Integration Guide for Materiel Development*. U.S. Army Human Engineering Laboratory Guide 1-69, 30 January 1969.

10. "Military Manpower Versus Hardware Procurement," HARDMAN Report. Washington, D.C.: Office of the Chief of Naval Operations, October 1977.

systematic inclusion of manpower criteria in system development.[11] It is our opinion, however, that without active support from the highest levels of the Army, this model will simply join its predecessors on the shelves of technical libraries.

Possible Solutions to the Problem

If human factors problems arise in military systems primarily from attitudinal and procedural reasons rather than from technological struggles with the unknown or state-of-the-art defects, shouldn't there be fairly straightforward ways of changing these defective attitudes and procedures? We think so. Unlike the civilian community, the process of attitude change among the military can be swift and efficient. All that is required is to persuade those at the top of the chain of command to support[12] a different attitude.

If the opinion-formers at the top cannot be persuaded, individual project managers can; however, no manager is likely to allocate scarce project resources to programs whose value he doubts. To persuade a manager to commit adequate resources to a human factors program requires first that adequate system performance be his ultimate goal, and second that he believes a human factors program is an efficient means of minimizing the performance gap. Following this, it is but a step to providing him with a human factors program tailored specifically to his project. When such a program is included in the government's procurement package, industrial offerors normally budget and staff for the human factors effort.[13] Moreover, there is at least some experimental evidence to suggest that a contractor's engineering staff will consider and effectively use human factors data when they are available and their use is required.[14] Therefore, in either case, persons with positive attitudes toward the potential benefits of a human factors program could overcome the defective government procedures which now inhibit fully successful human factors efforts.

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11. D. L. Burt, *et al.*, *Human Factors Engineering in Research, Development and Acquisition.* Bethesda, Md.: Andrulis Research Corporation, 1980.

12. "Support" as used here is a term of art. Senior commanders are prevailed upon daily to endorse a variety of allegedly worthy objectives. The torrent of new policies and regulations which professes these endorsements does not go unnoticed; but what people look to in identifying real support is which of their endorsements commanders keep asking about.

13 Where the government's procurement package ineffectively includes provision for a human factors effort, a diligent and sincere contractor may find himself underbid by a competitor with a good grasp of "design-to-cost" terminology and an implied understanding of the project manager's concern for meeting cost and schedule goals.

14. L. M. Lintz, *et al.*, "System Design Trade Studies: The Engineering Process and Use of Human Resources Data." Technical Report 71-24, Air Force Human Resources Laboratory, Wright-Patterson AFB, Ohio, June 1971.

MATERIEL ACQUISITION PROCEDURES

Materiel acquisition documents are the primary means by which the Army's needs for the future are communicated to materiel developers. Their contents, with respect to personnel considerations and training, have frequently been less than complete. This condition is often explained in some variation of the following: ". . . very few techniques are available for describing human resources data in terms that are meaningful to the design engineer."[15] Therefore, as observed in the "Nucci Report":

> Manpower, maintenance and training representatives attend design reviews for the purpose of refining and updating their requirements. But the documents do not require these groups to provide the design agencies data to serve as the basis of design and tradeoff analyses so that the design will be influenced by manpower factors. There is considerable effort to adapt man to the constraints built into the hardware, instead of using manpower factors as design criteria.[16]

The implications of this observation appear at first blush to be either that manpower and training proponents don't know how to communicate human resources data, or that designers are unwilling to bother with it. Neither, we believe, is correct. The key to communication between the groups is writing human performance specifications which are *testable.* Performance time and accuracy standards (exactly the sort of government specifications encouraged by OMB Circular A-109) *together with* stated limits on skill requirements and length and complexity of training will provide adequate communication with designers so long as objective verification is possible. The scenario for this communication has already been anticipated:

> The discussion so far has been focused on the typical materiel development process—materiel requirements are identified and then personnel and training requirements are deduced. In the past few years it has become obvious that the approach must be modified. Currently and in the future, people requirements may be more difficult to meet than materiel requirements. The traditional design relationship between materiel and personnel requirements may have to be reversed, placing both the materiel and the train-

15. C. Fink and W. Carswell, "Integrated Personnel and Training Information for TRADOC System Managers (TSM): Technical Gaps." ARI Research Report 1238, February 1980, p. 17.

16. E. J. Nucci, *et al.*, "Study of Manpower Considerations in Development," Volume 1. Washington, D.C.: Office of the Director of Defense Research and Engineering, October 1967, pp. 17-18.

ing/personnel developers into an unexplored area. In the immediate future the general requirement posed to the materiel developer may be: Given that the materiel will be manned by persons of a specific MOS and skill level, and that personnel quantities and training requirements will not exceed specified limits, design the materiel to meet these constraints.[17]

To implement this communication, the format of the materiel acquisition documents[18] should be modified to include realistic descriptions of the personnel who will eventually operate and maintain the new system. Also a "maximum training burden" should be set forth in hours or dollars for new system operators and another for maintainers (at each level). These are two legs of the materiel acquisition procedures stool. The third, and perhaps most important, leg is the specification of operation and maintenance performance standards under stated, realistic conditions.[19] Such performance specifications must be composed at a level which is testable. They normally should be written at the service school which prepared the original requirements and should be expressed in terms of performance, time, and acceptable accuracy.[20] When these performance specifications (which directly flow from the requirements of OMB Circular A-109) are linked to the stated constraints of training and personnel, the framework will have been created for materiel acquisition procedures which require adequate implementation of human factors in the design process.

When the materiel acquisition documents are complete—that is, when each includes an objectively verifiable set of human performance specifications to be achieved from personnel whose characteristics and training are described—the combat developer will have adequately expressed to the materiel developer not only what capabilities are needed, but also the extent of the resources available to achieve them. The materiel developer will then be in a position to describe to industry representatives the actual system (hardware, software, operators, maintainers, and training) which meets specified needs. In this way, the nature of the real system must be thought through before it is developed. The industry

17. Fink and Carswell, pp. 8-9.

18. Includes letters of agreement, letters of requirement, training device requirements, required operational capabilities, joint service operational requirements, and mission element need statements.

19. B. L. Berson and W. H. Crooks, "Guide for Obtaining and Analyzing Human Performance Data in a Materiel Development Project." Technical Memorandum 20-76. Aberdeen Proving Ground, Md.: U.S. Army Human Engineering Laboratory, September 1976, pp. 27-28; and Jonathan Kaplan and W. H. Crooks, "A Concept for Developing Human Performance Specifications." Technical Memorandum 8-80. Aberdeen Proving Ground, Md.: U.S. Army Human Engineering Laboratory, April 1980.

20. Where satisfactory accuracy is probable, it is usually more expedient to speak of errors (deviations from accuracy).

representatives are given explicit and clear descriptions of what the actual system must be able to accomplish to be minimally acceptable, and the design of the hardware and software components of that system must include the level of human factors input which will permit the specified performance with the stated personnel and training to take place.

The first point at which this new materiel acquisition procedure is communicated to industry representatives should be the request for proposal (RFP). The RFP should include the same set of constraints and standards set forth by the user in the materiel acquisition documents.

If the RFP adequately accounts for human factors by (1) imposing human performance (instead of human engineering design) criteria; (2) describing the pretraining characteristics and aptitudes of the intended user population; (3) stating the maximum permitted training burdens; (4) requiring the inclusion of a human factors engineering program (tailored from MIL-H-46855) designed to meet the performance specifications; and (5) requiring that all industry proposals contain a "manpower characteristics integration" section, the fidelity of performance of the successful contractor could then be assessed during testing.

TESTING PROCEDURES

There is an adequate and simple means to verify objectively at a relatively early point in system design that the hardware (and any software) has *in fact* been designed in accordance with the specified manpower characteristics. That means is the conduct of a human factors engineering (HFE) test. A standardized methodology for the conduct of such a test has been available since 1976 when contract data item description DI-H-1334A (Report of HFE Test) was published by the Army. The other services adopted nearly all of it when the DOD Human Engineering Test Report, DI-H-7058 was published in 1979.

Even though this testing may be planned, however, experience has shown that it is frequently not accomplished. Sometimes it is cancelled outright (usually when the project has more requirements than funds), but often it is simply postponed—until after the decision (IPR, ASARC, DSARC) which its results should have influenced. The usual justifications for this postponement are that "more important" testing had to be completed. Contrast that conception of relative importance with two observations made 5 years ago in a Pentagon document explaining life-cycle costing (LCC). One was:

> The LCC considerations of personnel skill levels and qualifications in support or operation of a weapon system must be given visibility and consideration early. . . . Recall that people costs are consuming the DOD budget.[21]

21. R. E. O'Donohue, Jr., "Life Cycle Costing," *Commanders Digest*, Vol. 18, No. 16, October 16, 1975. Arlington, Va.: American Forces Press Service, p. 5.

The other observation showed that:

> Too often, project performance improvements failed to materialize in the field, because of our failure to consider the potential impact of the new item in terms of number and calibre of people to operate and maintain it or that its increased complexity might result in less reliability and availability, and therefore higher LCC.[22]

Of significant threat to adequate testing are well-meaning attempts to speed up the materiel acquisition process.[23] Inasmuch as contractors are already nearly as pressed for time as they can be and still have reasonable chances of meeting delivery schedules, the only remaining time in the cycle which can be shortened is the government's. It should come as no surprise that, within the development community, the least popular government activity is testing. This is understandable, because while tests will hopefully confirm all of the claims about system performance made by the contractor and the project manager, they also often reveal a variety of defects in the system—many of them small—which may cast the system in a less-favorable light. If such tests could be eliminated, especially in the name of efficiency (time and cost savings) the decision to produce and field the system could be made relatively quickly. Correction of system design errors, or features which require manpower or training resources well beyond those available, or expensive hardware redesign, could be postponed until after the development is completed and the system is in the field. The apparent reduced cost produced by relatively quick, inexpensive testing would, however, have been translated into real-world, high life-cycle cost caused by the necessity to retrofit, alter training, recruit different individuals, or procure a new system. Here is how a recent analysis from the U.S. Army Training and Doctrine Command (TRADOC) explained it:

> Currently most new systems are being developed on an accelerated schedule, and there is a concerted effort to reduce the entire developmental cycle to about five years. This is being attempted through the elimination of DT/OT III, and the complete or at least partial elimination of DT/OT I. . . . As a consequence, it appears that many of the training and human factors considerations which should be addressed during Phases I and II of the LCSMM [Life Cycle System Mangement Model] are receiving, or will receive, minimum attention. It seems *probable*, therefore, that many of the

22. *Ibid*, pp. 7-8.
23. David T. Spencer, "Alternatives for Shortening the Acquisition Process." *Defense Systems Management Review* 2:4 (Autumn 1979):36.

> training system development problems which the Integrated Personnel Support procedures were designed to alleviate will instead be exacerbated by efforts to reduce and/or bypass major portions of the training system development process. (Emphasis added.)[24]

In our view, the testing which has the greatest potential for either aiding the development of a system or eliminating an entirely deficient one takes place at DT/OT I. Either the elimination of DT/OT I or their performance in an inadequate manner will be a major contributor to the acquiring and fielding of systems which are likely to have a severe performance gap. In the not very long run, this will result in much longer development time and greater amount of money spent on either retrofitting the system fielded, developing a new system, or losing the battle that the system should have helped win.

Conclusions

This paper has attempted to show that neglect of human factors during either system development or testing may result in the acquisition and fielding of weapons with significant gaps between designed effectiveness and the effectiveness actually achieved on the battlefield. We believe that there are two principal reasons for neglect of human factors—attitudes and procedures—and that the way most likely to overcome that neglect is to change system development procedures by adding to materiel acquisition documents the triad of personnel and training constraints and soldier performance specifications and by conducting developmental and operational tests (particularly DT/OT I) in which all three elements of the triad are measured and evaluated. The technology and methodology needed to effect and support those procedural changes exist today; all that is needed is for military managers to choose to use them. ||

24. Fink and Carswell, p. 20.

Systems Approach to Multinational Acquisition: NATO AWACS

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Dr. George K. Chacko
Lieutenant Colonel Bruce N. Stratvert, USAF (Ret.)

At their December 1978 Defense Planning Committee Meeting in Brussels, North Atlantic Treaty Organization defense ministers formally approved the multinational NATO airborne early warning and control (AEW&C) program. The crucial element of the $1.8 billion acquisition is the NATO E-3A airborne warning and control system (AWACS) aircraft with specially developed capabilities to detect low-flying aircraft over difficult European terrain. In his presentation to the 96th Congress, the Under Secretary of Defense, Research and Engineering, said:

> The multinational NATO AWACS program will be the largest, single commonly funded project ever undertaken by the Alliance. In taking this crucial step to counter the Warsaw Pact low-level air threat, NATO has demonstrated its military and political solidarity.[1]

The legal document representing this solidarity is the multilateral memorandum of understanding (MMOU). The signing of the MMOU by all the participating nations was imperative for the success of the acquisition effort. The participating nations are Belgium, Canada, Denmark, Germany, Greece, Italy, Luxembourg, the Netherlands, Norway, Portugal, Turkey, the United Kingdom, and the United States.

NATO's Largest Acquisition Jeopardized

At the November 1979 session of the NATO AEW&C Program Management Organization (NAPMO) Board of Directors, a member country announced her

1. Under Secretary of Defense for Research and Engineering, "The FY 1980 DOD Program for Research, Development and Acquisition Statement to Congress," Department of Defense, Washington, D.C., 1 February 79, p. IV-7.

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decision not to participate in the E-3A acquisition component of the AEW&C program.

To determine the cost impact of this decision on the NATO AWACS acquisition program, much more than the acquisition share of the non-participating country had to be considered. For instance, a "domino" effect of non-participation by other countries, as well as decreased participation in other acquisition elements, was a real possibility. While not solely due to the member country decision, the total impact of the decision was subjectively estimated at $98 million.

The U.S. government position on the announced non-participation by a member country had to be formulated before February 1980 in preparation for the board meeting that spring.

The U.S. position was developed and then presented at the spring meeting. As a result of deliberations at that and subsequent meetings, the objecting member country in the early summer agreed in principle to participate in the AWACS acquisition. On May 7, 1981, the country announced that it would fully participate in the AWACS program.

Systems Approach to Problem Analysis

This paper describes our systems analysis approach to determining the impact of re-scoping the AEW&C program to accommodate the possible non-participation by a member country. This analysis was used in support of Air Force efforts directed toward formulating the U.S. position on the issue. We will draw upon our approach to this particular NATO problem to suggest elements of systems approach that may be applied to multinational acquisition in general, recognizing full well that one swallow does not a summer make. We hope that the systems approach elements developed here will contribute to a constructive dialogue in the arena of multinational acquisition.

Four Elements of Systems Approach

It has been suggested that there are four elements essential to systems approach to any problem.[2] These elements are as follows:

(1) Context
(2) Cost
(3) Effectiveness-absolute
(4) Effectiveness-relative, i.e., sensitivity

2. George K. Chacko, *Systems Approach to Public and Private Sector Problems*, North-Holland, Amsterdam, The Netherlands, 1976, Ch. 3; "Systems Approach to Policy Perspectives of Cause and Cure," in *Health Handbook*, North-Holland, Amsterdam, The Netherlands, 1979; and *Management Information Systems*, Petrocelli, Princeton, N.J., 1979, Ch. 3.

Context is the perception by the decision-maker of the external and internal boundaries.

Costs are of two types: (1) cost of opportunity foregone, and (2) cost of opportunity acquired. In the familiar use of the term "cost," the marginal principle is implicit. The contribution of an additional unit of the same kind to the total utility (potential satisfaction) is *marginal utility*. The allocation of resources among different activities must be in accordance with the marginal principle—that $1 invested in any one activity must yield the same satisfaction as $1 invested in any other available activity.

What happens when the $1 is to be invested in an activity, the like of which is not available? Recalling that the basic requirement of the marginal principle is that the additional unit be "of the same kind," the inadequacy of marginalism emerges. Thus, to guide the allocation of resources for the lunar landing mission, there was nothing "of the same kind" to guide the marginal allocation of resources so that $1 in aerospace could be considered, say, as an additional $1 in aircraft. The investment in aerospace had to be considered as a *de novo* activity, justified as such. Costs are incurred for one reason: The system should perform. The performance can be identified in terms of, or separate from, the physical characteristics.

Effectiveness-absolute is the ratio of actual performance to desired performance. Efficiency is a similar ratio, with the exception that the denominator is the maximum, instead of the desired, performance.

More than the absolute measure of performance of the subsystem (or the system), the proportionate change in the *system* performance corresponding to the proportionate change in the *subsystem* performance (effectiveness-relative) is of greater interest to the decision-maker. The proportionate change indicates to him the combined effects of the interactions, some of which he (she) may be able to ignore intelligently.

The contribution of the systems approach is in assisting the decision-maker to allocate resources on the basis of the sensitivity of the system objective to the policy activity chosen, identifying the cost of the policy and at least one alternative, cost being not only opportunity foregone, but also opportunity acquired.

Systems Approach (SA) Element 1: Context

We will discuss the four elements of systems approach to multinational acquisition, drawing upon the systems approach employed in this particular NATO problem, numbering sub-elements of 1 as 1.1, 1.2, etc.

SA ELEMENT 1.1: IDENTIFY SYSTEM OBJECTIVE(S)

Under the NATO treaty, the primary purpose of the alliance is to maintain the security of member nations by deterring aggression, and should aggression occur, to re-establish the territorial integrity of the North Atlantic area.[3] NATO's ability to provide warning against low-level hostile aircraft plays a critical role in deterrence of Warsaw Pact attack. This deterrence is achieved by having forces able to respond in a timely/flexible manner to a given level of attack. There must also be a linkage of the various elements contributing to this capability—warning of attack, air power strength/effectiveness, etc.—so as to make it clear to a potential aggressor that any attack on NATO will involve excessive risks to himself.

SA ELEMENT 1.2: IDENTIFY ADMINISTRATIVE HIERARCHY

It is one thing to identify the system objective(s); it is quite another to identify the "players." In identifying the players, the organizational schemata are less important than the *de facto* lines of communication, both up and down. In Figure 1, the administrative hierarchy is presented. Note that the lines from the highest level of decision-makers, *K*, to the next tier, *G*, are dotted, indicating that the hierarchy is *de facto* and does not appear as such in the organization chart. It is most helpful if the administrative hierarchy can be expressed in three tiers. The advantage of a three-tier presentation is that *K* is at the system level, *G* at the subsystem level, and *D* at the sub-subsystem level so that the minimum group of effective decision-making and decision-implementing are directly identifiable.

SA ELEMENT 1.3: IDENTIFY PERFORMANCE MEASURE (DIRECT OR SURROGATE) OF THE SYSTEM

Drawing directly upon the NATO treaty we identified deterrence as the objective associated with AWACS acquisition. How can deterrence be measured?

The Joint Chiefs of Staff define deterrence as "the prevention from action by fear of the consequences. Deterrence is a state of mind brought about by the existence of a credible threat of unacceptable counter action."[4]

NATO has termed the E-3A a Priority I requirement, i.e., a requirement of such critical importance that, without its implementation, the very survivability of NATO forces is jeopardized.[5] The principal mission of AWACS is low-level

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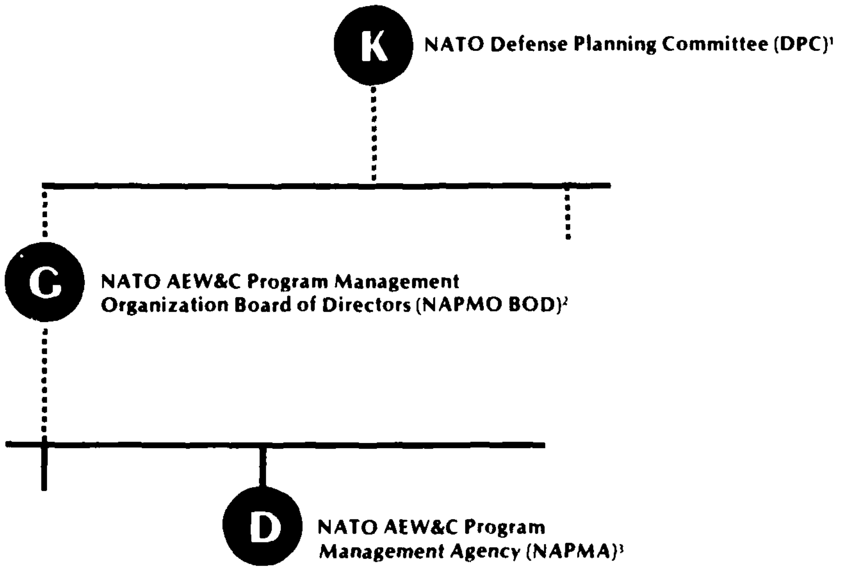
3. NATO Information Service, HQ NATO, *NATO Handbook*, Hazel Watson and Viney, England, March 1978, p. 16.
4. JCS/J-1, JCS Pub 1: "Department of Defense Dictionary of Military and Associated Terms," U.S. Government Printing Office, Washington, D.C., September, 1974, p. 107.
5. SHAPE/XR, "Tri-MNC Statement of Operational Requirements for a Land-based AEW System," HQ SHAPE, Mons, Belgium, August, 1975, p. 1.

FIGURE 1
Administrative Hierarchy



1. Committee of the North Atlantic Council (highest authority of the Alliance) for discussion of NATO military policy; composed of representatives of the countries which take part in NATO's integrated defense.

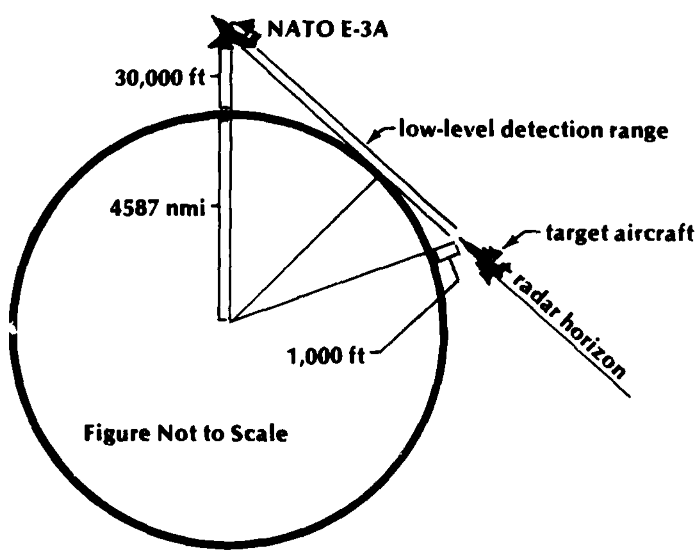
2. Executive agency for NATO E-3A program; responsible for policy formulation; responds to NATO requirements; comprised of one member per participating nation.

3. Directly manages NATO E-3A program; located at Brunssum, the Netherlands; internationally manned: PM is FRG MGen, 51 U.S. personnel of 200 total.

warning. In Figure 2, the geometry associated with the E-3A is shown at its operating altitude of 30,000 feet, with a low-level target at 1,000 feet. Using appropriate calculations, we find that E-3A provides a mean warning time of 24.2 minutes at an attacker speed of 500 knots.

How can we translate into warning time the consequences of non-participation by a member country in the AWACS acquisition? If we say that $98 million

FIGURE 2
NATO E-3A Low-Level Radar Line-of-Sight Coverage



could represent the non-purchase of two E-3A aircraft[6] out of the 18 required for NATO, then we could calculate the difference in warning time between one aircraft and three. We find that the mean warning time with three aircraft is 26.9 minutes, i.e., 2.7 minutes more than that provided by only one aircraft.

What does the 2.7 minutes "buy"? A high-performance Warsaw Pact aircraft, traveling at 500 knots, covers 25 nautical miles in 3 minutes. If we consider an interceptor also traveling at 500 knots, 3 minutes additional warning time means that the intercept will occur 3 minutes sooner. What the 3 minutes "buys" is a city; for instance, Hamburg is only 26 nautical miles from the East German border.

6. Boeing Aerospace Company, "NATO Production Letter Contract CCP 4463," The Boeing Company, Seattle, Wash., August 1979, p. 40.